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TESTING THE QUALITY OF FLOUR BY THE RECORDING DOUGH MIXER [1]

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Introduction

The characteristics of dough and the quality of the resulting bread depend on a number of factors. These factors may be classified into three groups: First, those due to the protein or gluten structure; second, those arising from substances in the wheat other than protein; third, those due to substances other than flour used in making the dough.

Characteristics depending on the first group of factors are fixed primarily when the protein is laid down in the endosperm, and secondarily by the external conditions during harvest and storage. These factors are then, to a large extent, inherent in the wheat, but may be influenced by treatment subsequent to harvest. Gas retention, and hence to a certain extent fermentation tolerance, depend largely on this group of factors.

The second group of factors includes the starch, fatty or lipoid material, inorganic constituents, some sugar, and enzymes. Since starch is present in about six times the amount of the protein, and since that from different wheats varies, starch, no doubt, has an influence on quality, but it has not been possible to measure this influence satisfactorily. The influence of the phosphatides present in the wheat has been noted by Working (1924, 1928). Gas retention is influenced to some extent by this second group of factors. The enzymes are factors of considerable importance in this group since they may determine to some degree the gas producing capacity of the dough.

The third group of factors influencing dough includes the materials added in its mixing such as water, sugar, fat or shortening, salt, and yeast. The water in the dough apparently exists as adsorbed and free water. The water is adsorbed on the surfaces of the starch granules and on the protein material. The free water probably exists as films

[1] Contribution No. 43, Department of Milling Industry.

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on the surfaces of the starch and the protein. It is this free water which is of most importance in giving dough its plastic and elastic properties. The demarcation between free and adsorbed water is not sharp. Adding the amount of water necessary to form a dough of the correct stiffness is still largely in the realm of art. Yet it is not possible to get a correct measure of the quality of flour without means of measuring absorption with some degree of accuracy. The fat and the yeast have a minor influence on the consistency of the dough, while the salt adds considerably to its stiffness.

In measuring the quality of wheat, the first group of factors are of the most importance since they are inherent in the grain and can be compensated for only to a limited extent. Deficiencies due to the second group may be largely corrected by a proper balancing of the third group. In testing the quality of wheat varieties we are mostly concerned with the first group of factors since they are inherent in the wheat. To a certain extent deficiencies due to these factors may also be corrected, but that is a problem for the practical baker. This paper is an endeavor to present a method of measuring quality as far as that is related to protein or gluten structure.

The gluten in dough may be pictured in the form of a complex mesh-work in which the starch and other materials are held. The chief binding forces are closely associated with the water, adsorbed and free. Ultimately they may be electrical in nature. The water films on the gluten mesh-work and the starch form the membranes which hold the gas bubbles in the dough. The thicker these films within limits, the less resistance there will be to movement among the dough particles. It is for this reason that the amount of water used in making the dough is so important in measuring its propreties.

Development of Devices to Measure the Physical Properties of Doughs

The main problem in determining quality of flour, as far as quality is dependent on the wheat, is to measure the characteristics of the gluten structure. Various means and methods have been proposed to measure quality in this way. Among these may be mentioned: the Chopin Extensimeter, the Bühler Comparator, and the Brabender Farinograph. In the following text will be given the evolution and the description of the present Recording Dough Mixer.

The first attempt in this laboratory to measure directly the physical properties of the dough was by means of a dough mixer which had four moving pins revolving in a planetary system. The central gear was connected with a spring steel rod 40 inches long. As the pins revolved and the dough developed, the amount of resistance was regis-

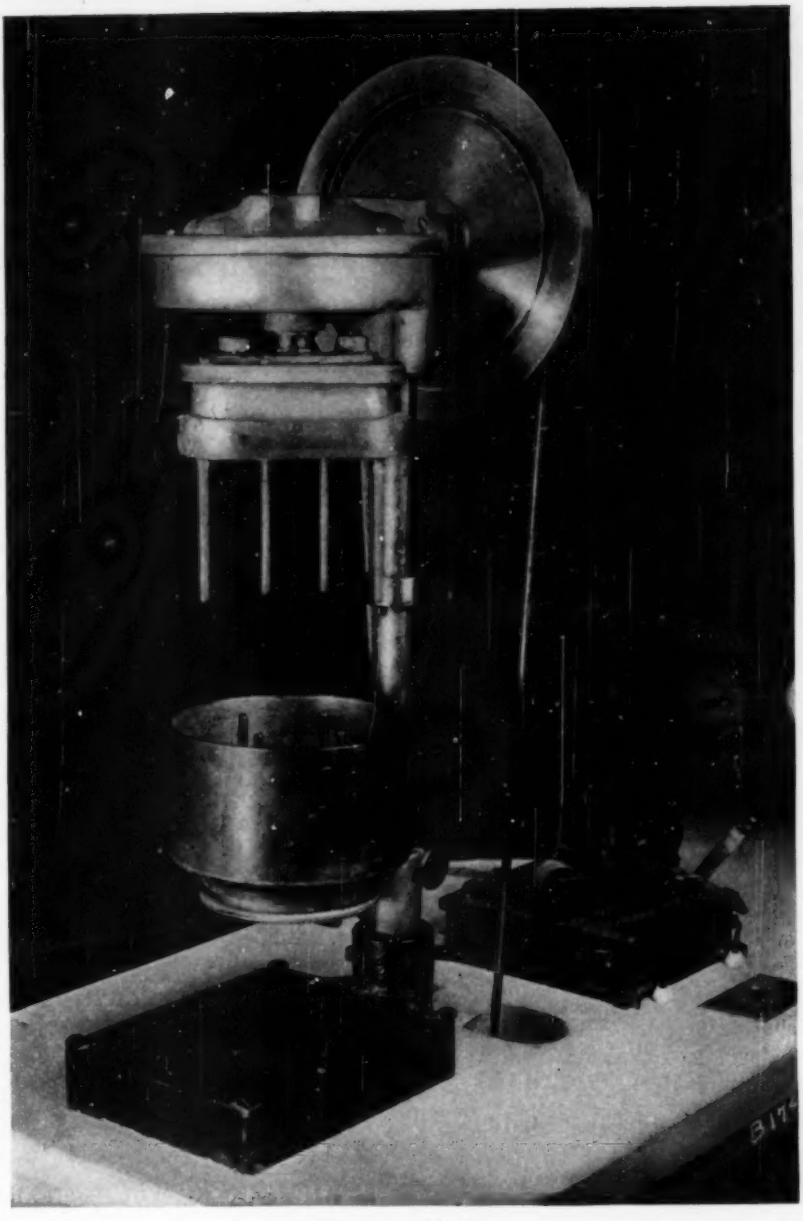

Fig. 1. Dough mixer.

tered by the amount of twist on the rod. As a mixer it was a fair success, but for measuring resistance of the dough there were two difficulties—the dough would ride around more or less on the moving pins, and there was no dampener or shock absorber.

To prevent the dough from riding around on the moving pins, three fixed pins were placed on the bottom of the bowl. The placing of fixed pins in the bowl necessitated a definite path of movement for the movable pins with reference to the fixed pins. Because of this, it was necessary to abandon the idea of using the twist on the rod to indicate the stiffness of the dough. This mixer has been described by Swanson and Working (1926).

A third mixer much more sturdy in construction and having four fixed pins instead of three was constructed. This machine, which is illustrated in Figure 1, has been used in all wheat testing of this department for 6 years, and is still in use for certain types of work.

Figures 2 to 5 illustrate the appearance of doughs mixed in this machine for varying lengths of time. Figure 2 illustrates dough which was mixed one-half minute. It was not developed as shown by its incoherence. Figure 3 shows dough mixed 2 minutes. This had reached maximum development as shown by its strength in clinging to the pins when raised from the bowl. For many flours even this amount of mixing would be too much. The chief advantage of this type of mixing is that all parts of the dough are equally developed. Figure 4 illustrates dough that had been mixed for 7 minutes. The broken down character of the dough is evident. Such dough would be entirely unsuited for baking by the ordinary method of fermentation. It is not possible to wash gluten from such dough. Flours from certain wheats break down to this extent in 3 or 4 minutes. Figure 5 illustrates the result of mixing for 15 minutes. The dough was completely broken down as shown by the lack of all dough characteristics. The mass resembles a paste of starch and water, all the gluten fibrils apparently having been torn to shreds.

The rate at which doughs develop to the condition illustrated in Figure 3, and also the rate at which they break down to the condition illustrated in Figures 4 and 5 are definitely related to characteristics inherent in the wheat. Flours from certain wheats develop much more quickly and break down much more rapidly than from others. This observation has been of great help in measuring the quality of wheat as far as that depends on variety or genetic factors. The reaction of flour towards mechanical action is very consistently related to varietal inheritance.

The observation of the varying reaction of flours towards mechanical action suggested the desirability of a method of accurately measur-

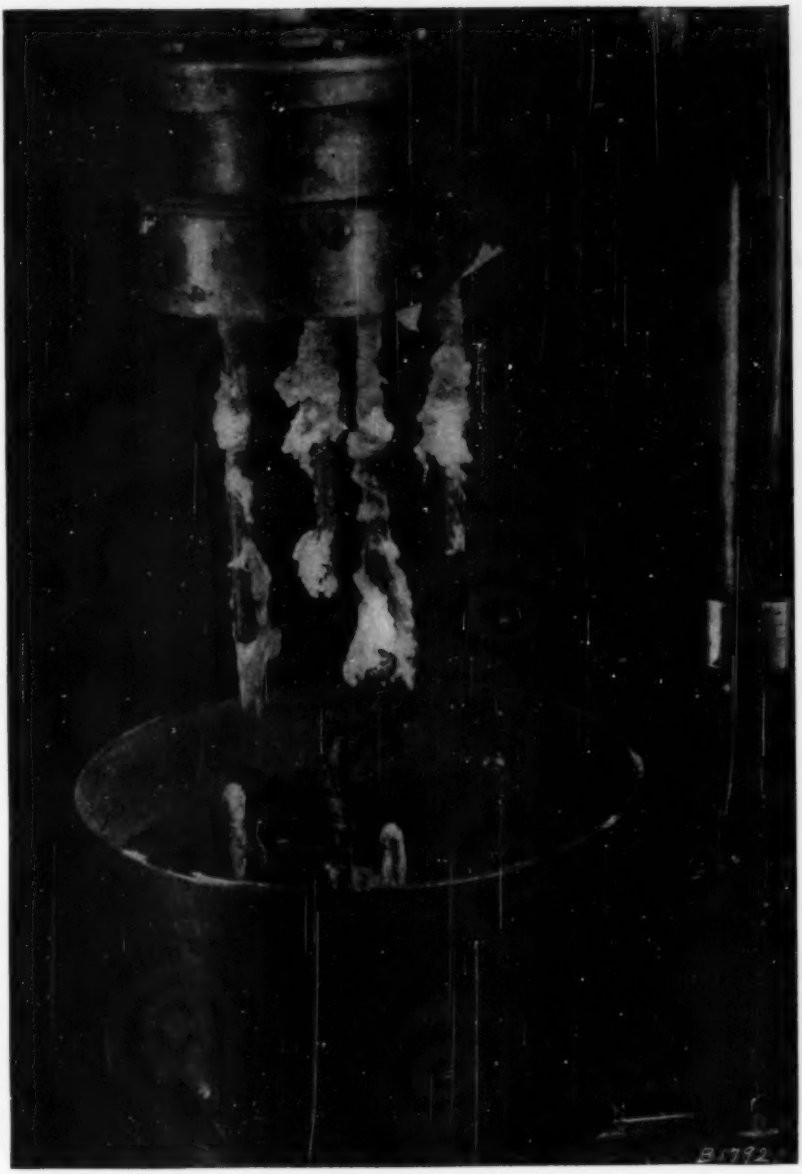

Fig. 2. Dough mixed one-half minute.

Fig. 3. Dough mixed 2 minutes.

Fig. 4. Dough mixed 7 minutes.

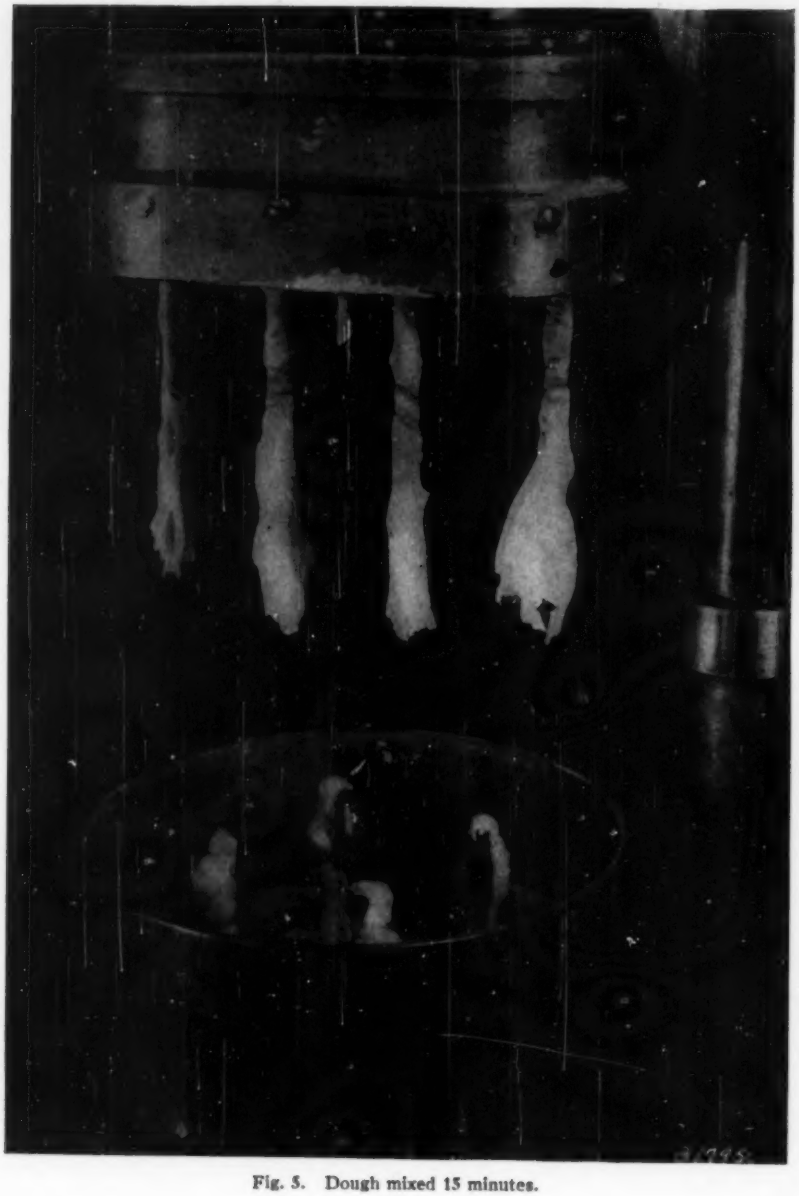

Fig. 5. Dough mixed 15 minutes.

ing this characteristic. The first method tried was to record the resistance offered by the dough by means of the wattmeter illustrated in Figure 6. This traces a curve on cross-section paper, reading from right to left, or the opposite of usual curves. As the water is incorporated with the flour and the dough develops, the curve rises to a maximum and then descends. The steepness of the rise, the height of

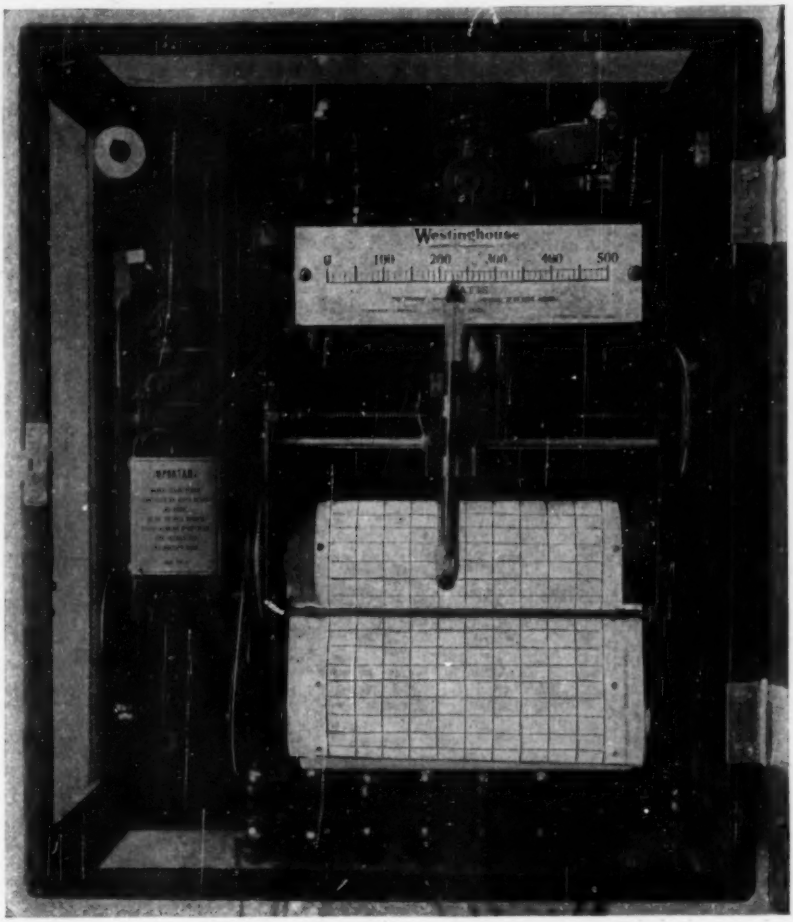

Fig. 6. Wattmeter.

the curve, the abruptness of the turn, and the descending slope are all associated with definite characteristics of the flour.

Figure 7 illustrates four characteristic curves recorded with the wattmeter. The upper left curve is a typical curve obtained from the flour of a high protein (17.2%) Blackhull wheat. The lower left curve is from a flour milled from a low protein (9.3%) Blackhull wheat. The

steepness of the ascending curve and the abrupt descent after reaching maximum stiffness is characteristic of flour from Blackhull wheat. The upper right curve is from flour milled from a high protein (16.6%) Turkey wheat, and the lower right curve is from a flour milled from medium protein (12.4%) Turkey wheat. Both of the Turkey wheat flours gave a much more gradual slope and less abrupt turn at maximum stiffness than did the flours milled from Blackhull wheats. The

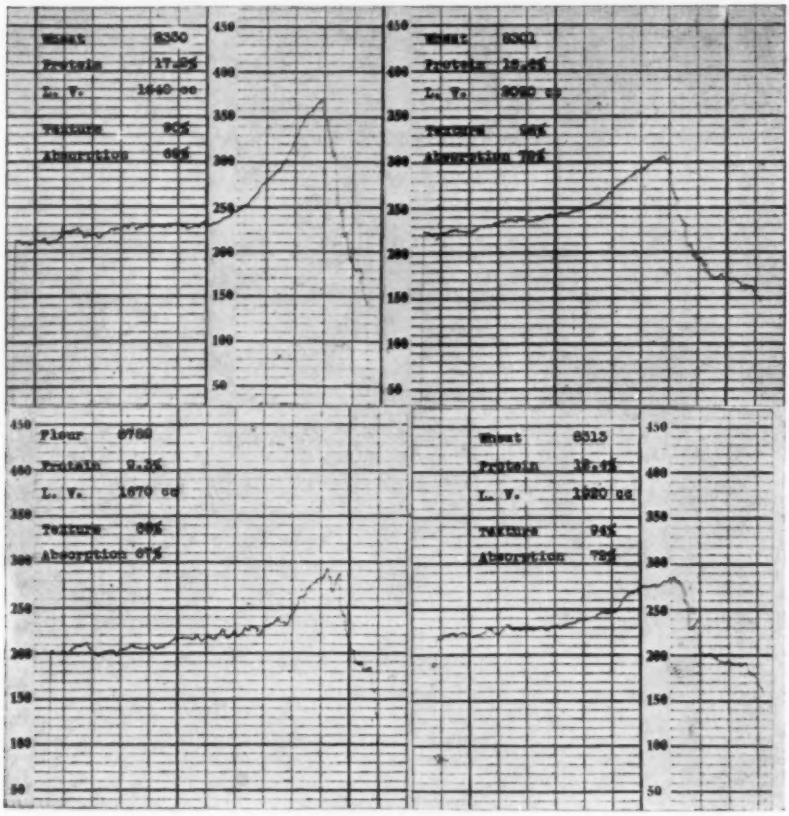

Fig. 7. Typical curves from varieties.

maximum height of the curve is apparently related to the protein content and to the amount of water used in making the dough. At the time these curves were made no accurate method of measuring absorption was available. An accurate mechanical method for this determination has now been devised and hence this variable is eliminated in the work as done at present. The relation of protein content as well as protein quality to the height and character of the curve is now a subject for study.

Two drawbacks were noted to the use of the wattmeter for tracing the curves. In the first place, if the total input of energy is measured, over half of this is friction and electrical losses. It was possible to get fairly accurate comparisons of flours tested within a short period of time, but when the tests were made under varying conditions there was some doubt as to comparative values. In the second place the wattmeter with the direct current was dampened in such a way that the curve was smooth making it difficult to tell the point at which the dough began to break and when it was completely broken down.

With the substitution of alternating for direct current another difficulty arose. While with the direct current all the small irregularities which help to interpret the characteristics of the dough were smoothed out, with the alternating current a continuously irregular curve was obtained. Figure 8 shows 7 curves made with flours from as many varieties. The mixing time for each was 15 minutes. From previous work it was known that breaking down commenced at about 5 minutes and was complete in 15 minutes. The curves do show that the Blackhull group have the steep slope and the abrupt turn, while the Turkey group have a more slanting slope and a less abrupt turn.

The difficulties in interpreting the curves from this machine prompted the desire for a mixer that would completely eliminate friction from the measurements, and record accurately the changes which the dough undergoes under mechanical action. A fourth mixer, employing the principle of measuring the resistance of the dough by the twist-in-a-rod, was designed and constructed with the help of W. W. Carlson, Professor of Shop Practice, Kansas State College. However, since it was necessary to retain the fixed pins in the bowl, it was also necessary to keep the circular movement of the bowl within approximately 1/8 inch. By adapting the principle used in platform scales this amount of movement was sufficient, if multiplied several times in the levers making connections with the recording pointer and pen.[2]

In Figure 9 are illustrated the bowl with the mixing head raised by its supporting elbow. Elevation to this position is accomplished by the crank shown at the right. When it is desired to remove the dough from the bowl, this mixing head is swung back 90° or as much as needed to leave the top of the bowl free for the operator. The bowl is clamped in a support which rests on ball bearings and is held in position by a vertical shaft extending downward. The position of the bowl in its support must be fixed and this is accomplished by a blunt steel

[2] The authors desire here to express their indebtedness to W. W. Carlson for his very valuable help. The present mixer, as well as the previous ones, were constructed in the college shops under his direction.

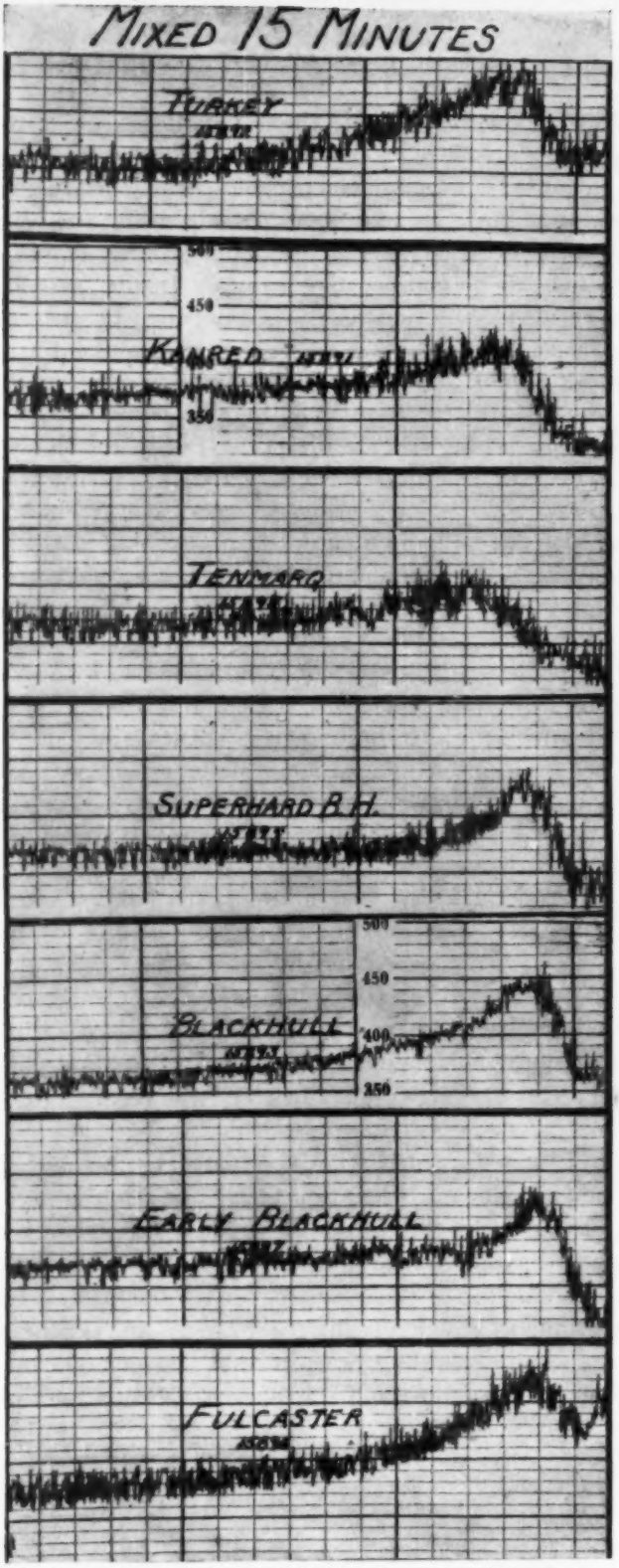

Fig. 8. Curves from varieties recorded with wattmeter and alternating current.

key in the support which fits into a slit in the bottom rim of the bowl. The recording device is shown in the background.

The supporting mechanism is so constructed that lowering can take place only when the upper pins are in correct position with reference to the fixed pins in the bowl. The bowl is clamped and loosened from its position by the bolt shown in the lower front.

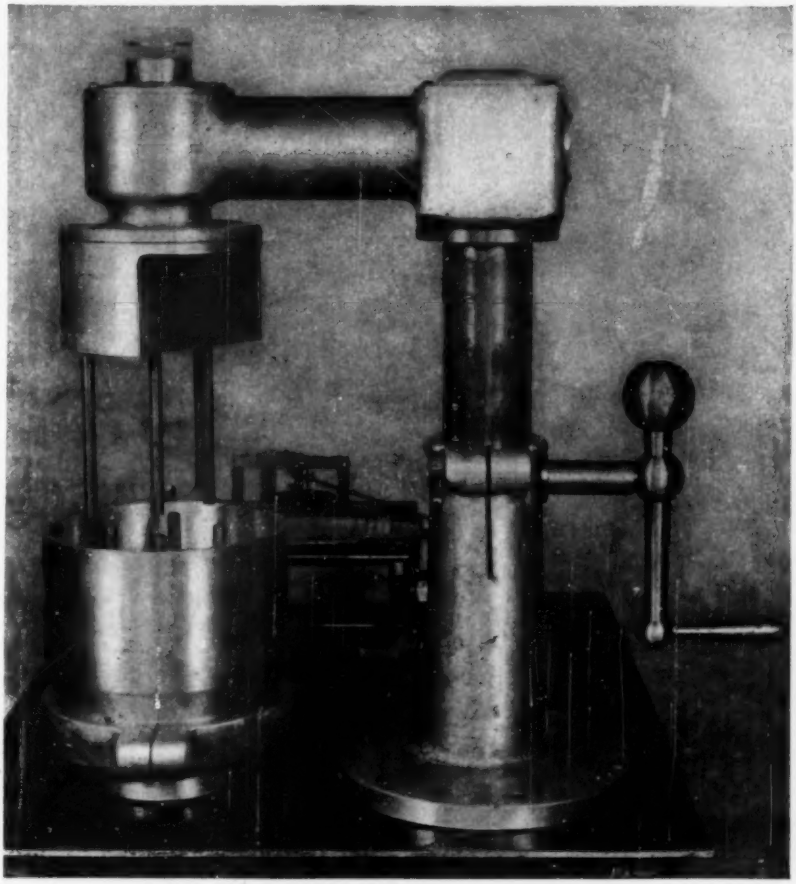

Fig. 9. Mixing head and bowl of recording dough mixer.

The path described by the upper pins relative to the position of the lower pins is shown in Figure 10. It was this diagram which showed that there could be a small amount of twist of the bowl without appreciably changing the relation of the fixed pins to the moving pins.

A side view of the whole mechanism is shown in Figure 11. The supporting framework for the mechanism is a steel table. The four large castors are adjustable so as to permit careful leveling. The large

wheel (a steering wheel from a motor car) serves to change the operating speed of the mixing head which holds the moving pins. There are four speeds available, namely, 36, 54, 81, and 122 r. p. m., of which the latter two are most useful. Just behind the wheel can be seen the shaft which holds the bowl support in position. The lower end of this shaft is held in a ball bearing supported on the lower platform which also supports the motor. It was found necessary to have this shaft of considerable length in order to prevent any side rocking of the bowl support and its connection with the recording device. The recording device is shown to the left on top of the table.

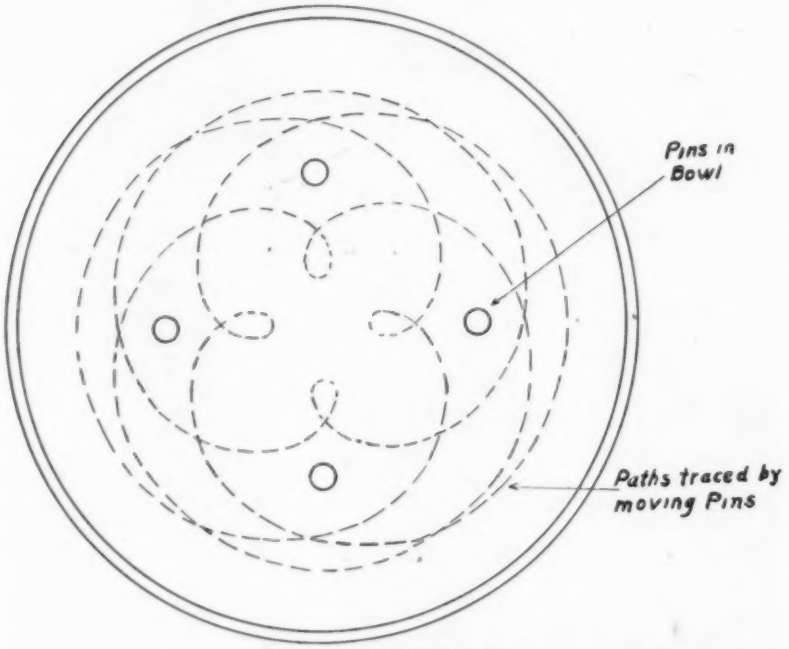

Fig. 10. Path of moving pins.

A skeleton diagrammatic side view is illustrated in Figure 12. This shows the ball bearing supports for the shaft which holds the bowl base in position. The broken line just under the table top indicates the lever which connects the bowl support with the recording mechanism. The lateral to and fro movement of the end of this lever is $\frac{1}{2}$ inch, but this is sufficient to move the pen and indicator or pointer the required distance. At the left end of the table is seen the weight and its regulating support.

One of the most puzzling problems in connection with the construction of this machine was how to measure the force exerted at the end of the lever from the bowl support. This was accomplished by em-

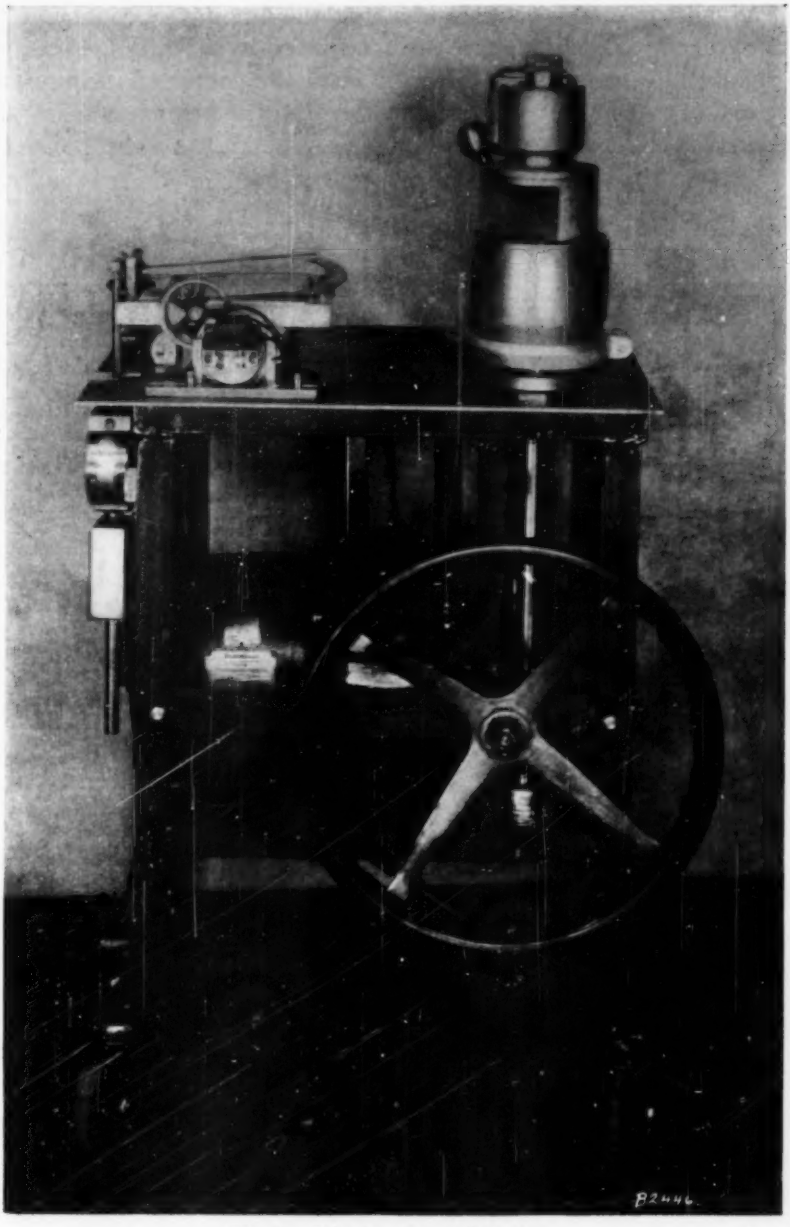

Fig. 11. Side view of recording mixer.

ploying the principle used in springless scales, namely, a weight which would measure the force by the amount of lateral displacement. The chief advantage of this scheme was that the amount of resistance to the force exerted could be most easily adjusted by altering the mass of the weight and changing its distance from the center of its support. Since it was known only very roughly how much the force was, it was necessary to have an easy method of adjustment.

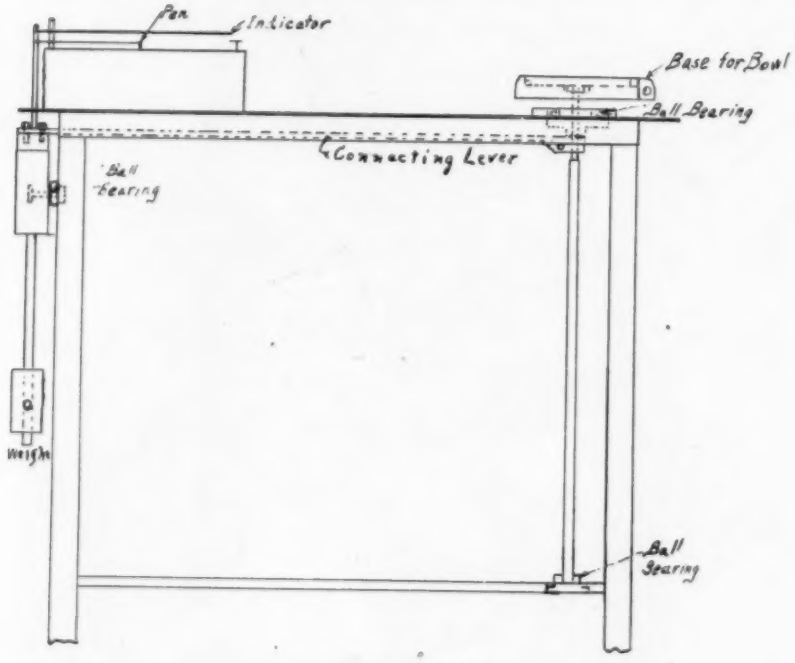

Fig. 12. Skeleton side view.

In Figure 13 is illustrated a rear view of the recording mixer. In the foreground to the right and just under the table top is the rectangular prism shaped weight and its circular support. The perpendicular small shaft extending above the top of the table connects the end of the lever arm from the bowl support to the recording mechanism. The upper end of this shaft must move exactly the same distance to and fro as the lower end. Hence there must be provided horizontal movement in connection with the circular movement of the weight support. This is accomplished by three flat steel bands wound partly around the circular weight support. This allows an absolute to and fro horizontal motion to the support of this shaft.

One of the very necessary problems to solve in connection with this recording dough mixer was the designing of a satisfactory dampener

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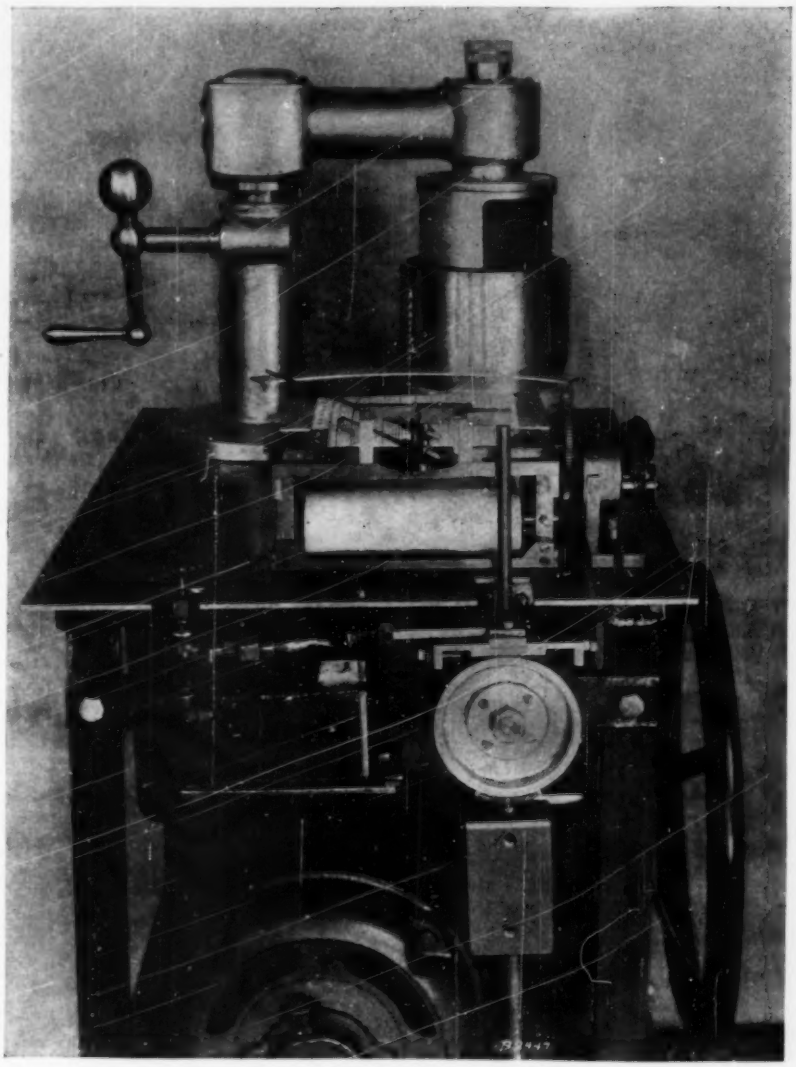

Fig. 13. Rear view of recording mixer.

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or dash pot, for without a dampener the whole recording mechanism would be of much less value. The requirements of such a dampener were, sufficient sturdiness and capacity to absorb any of the jerkiness due to the uneven impacts of the pins on the dough, and almost complete elimination of friction. It must also be capable of fairly wide regulation since the magnitude of the shocks to be absorbed was unknown. Complete shock absorption was not desired since a certain amount of the impacts should be recorded.

The device finally adopted is illustrated to the left of the weight support in Figure 13, and the outline of the construction is illustrated in Figure 14.

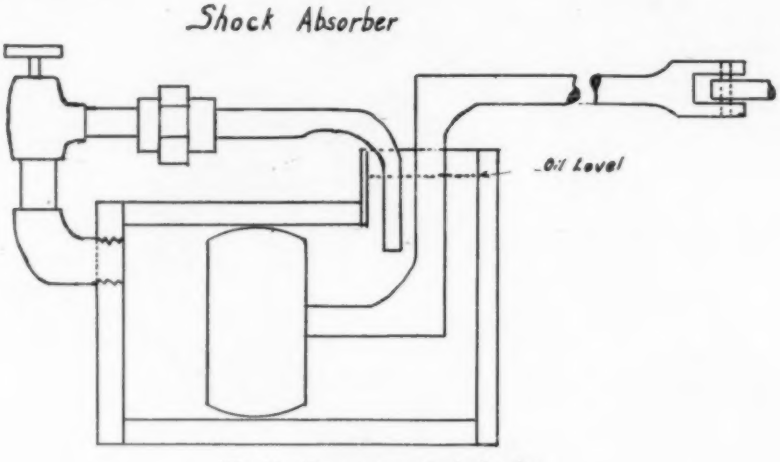

Fig. 14. Dampener or shock absorber.

The plunger is made of brass in the form of a sphere with two segments cut off in parallel planes. This construction allows the minimum of contact with the cylinder and prevents any binding. The cylinder is made of cast iron. By having a double elbow connection to the plunger up through a well, no stuffing box connection with consequent friction was necessary. This construction also does away with all oil leaks. By opening or closing the regulating valve, any amount of shock absorption desired may be secured.

A top view of the connection between the bowl support and the recording device is illustrated in Figure 15. This serves to bring out how a very slight twist on the bowl and support is sufficiently multiplied to give the necessary motion to the pen and indicator.

A top view of the recording device as seen from the position of the operator is illustrated in Figure 16. The roll holding the chart paper is moved forward during the operation by a Telechron motor seen to the left. The chart may be made to move at several different rates of

speed; the one used for tracing the curve illustrated in Figure 16 was one minute between cross lines. The position shown is at the end of exactly 5 minutes. The motor is the same as used in high grade Telechron clocks, and hence the cross spaces on the chart are exactly 60 seconds apart. The pointer is connected with the same mechanism as the pen and moves synchronously with it. The pointer makes it a little easier to read the position of the pen at any moment. The connection to the Telechron motor is controlled by a switch separate from the one which operates the mixer. Hence it is possible to move the chart forward to a convenient stopping place after stopping the mixer and to operate the mixer without using the recording device. The second speed (81 r. p. m.), continued for 10 minutes, appears best for drawing curves. When this length of time is employed, however, the dough is much over-developed for baking, and if a complete curve is wanted, the dough cannot be used for baking.

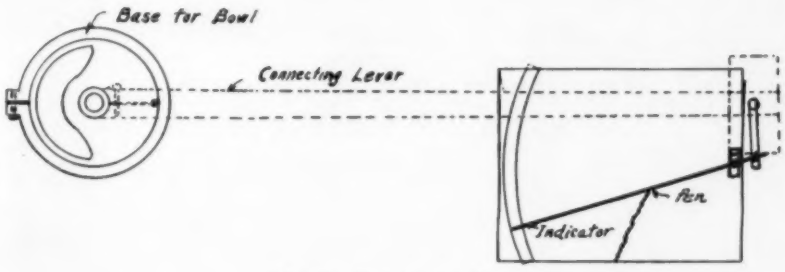

Fig. 15. Skeleton top view.

Doughs have been prepared using tap and distilled water. The mineral in tap water stiffened the dough and the characteristics of the curve were sufficiently different to show that it is necessary to use water of constant composition. Doughs were also mixed at different speeds and the curves seemed to show that the time of development, as well as the breaking down, is very much longer with the lower speeds (36 and 54 r. p. m.). The height of the curve is also very much lower. The high speed has the advantage in time, the dough both developing and breaking down more quickly. The second speed (81 r. p. m.) probably gives a better differentiation among flours that are close together in their characteristics. The effect of variations in the amount of dampening by the regulating valve upon the type of curve were studied. Too little dampening gives a decidedly zigzag curve even after the dough has broken down.

Curves were also made to ascertain the effect of salt alone, sugar alone, and both together. Salt has a stiffening effect and hence a constant amount of this ingredient should be employed when doughs

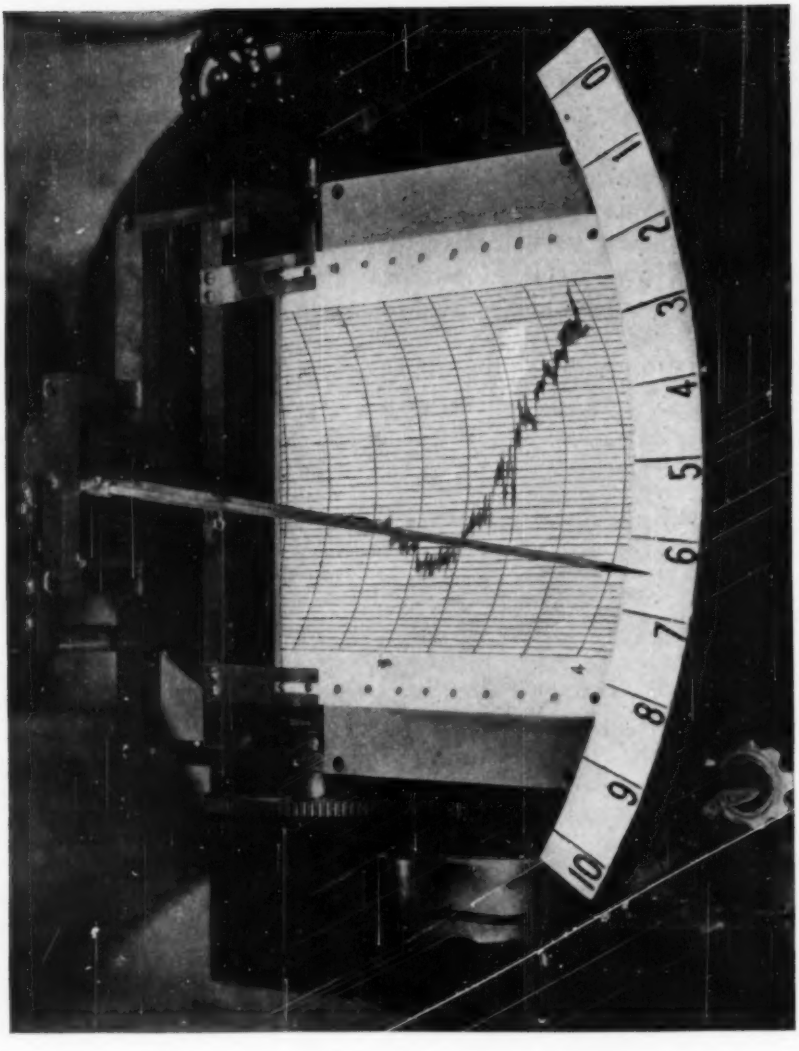

Fig. 16. Top of recording device.

are to be compared. Yeast and shortening were found to have very little influence on the character of the curve.

To show the possibilities of this recording dough mixer, a number of characteristic curves are given. Figure 17 illustrates the uniformity of curves when made from the same flour under like conditions. These curves were recorded from a 97% hard winter wheat flour, having 11.5% protein. This is representative of an average bakers' flour. The development of the dough is complete at the end of 3 minutes. The breaking down commences after 4 minutes, and at 6 minutes the dough is well broken down, and apparently complete at the end of 8 minutes.

To ascertain the effect variations in the amount of water would have upon the type of curve, the curves shown in Figure 18 were recorded from the same flour to which was added 63%, 67%, 71%, and 75% of water, respectively. Previous work with this flour had indicated that 67% water was as near the correct absorption as possible to determine. Figure 18 illustrates the four curves obtained. Too low an absorption increases both the steepness of the up slope as well as the height. It also increases the amplitude of the vibration or the zigzagging. Too high an absorption has opposite effects.

Mechanical Method for Determining Water Absorption

These four curves differ enough in characteristics to indicate that if this method is to be of much value, especially if closely related flours are compared, it is necessary to use an amount of water that is as nearly correct and uniform as possible for the flours tested. An accurate mechanical method for determining absorption has been developed in this laboratory. The method requires the use of a Sharples Super-Centrifuge. A suspension of 100 gms. of flour in about 600 cc. of water is prepared and passed through the centrifuge at a speed of 15,000 r. p. m., an additional 400 cc. of water being used to wash the flour into the bowl. The amount of water held by the flour against the centrifugal force is readily determined by weighing the dry spindle and the spindle with the retained dough. This method has been checked with the conventional method and in numerous baking tests and found to give a dough of the proper consistency for baking. The method is entirely independent of the personal equation, depending solely on the water holding power of the flour against a constant centrifugal force.

The development of temperature in dough while mixed is an important consideration. Just what useful information may be obtained from a study of temperature rise has not been investigated. From the observations made so far it appears to be of minor consequence in these determinations. It is true that the bakers use temperature rise as a

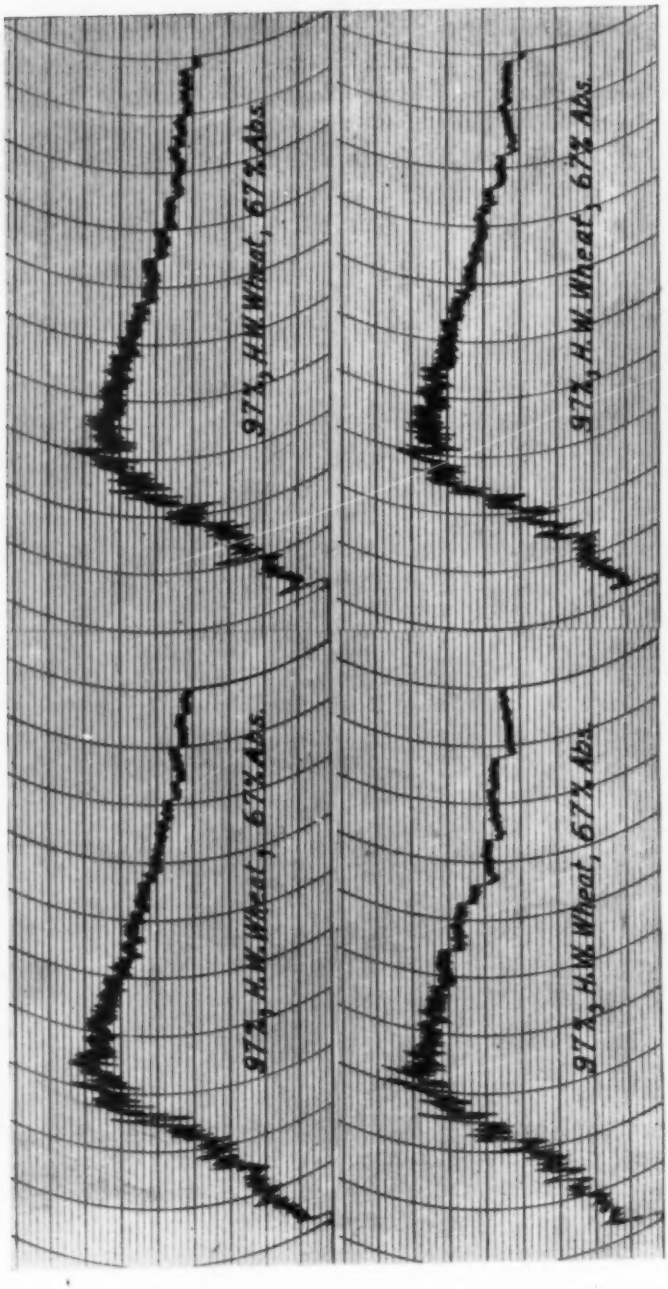

Fig. 17. Experimental variation in curves recorded with the recording mixer.

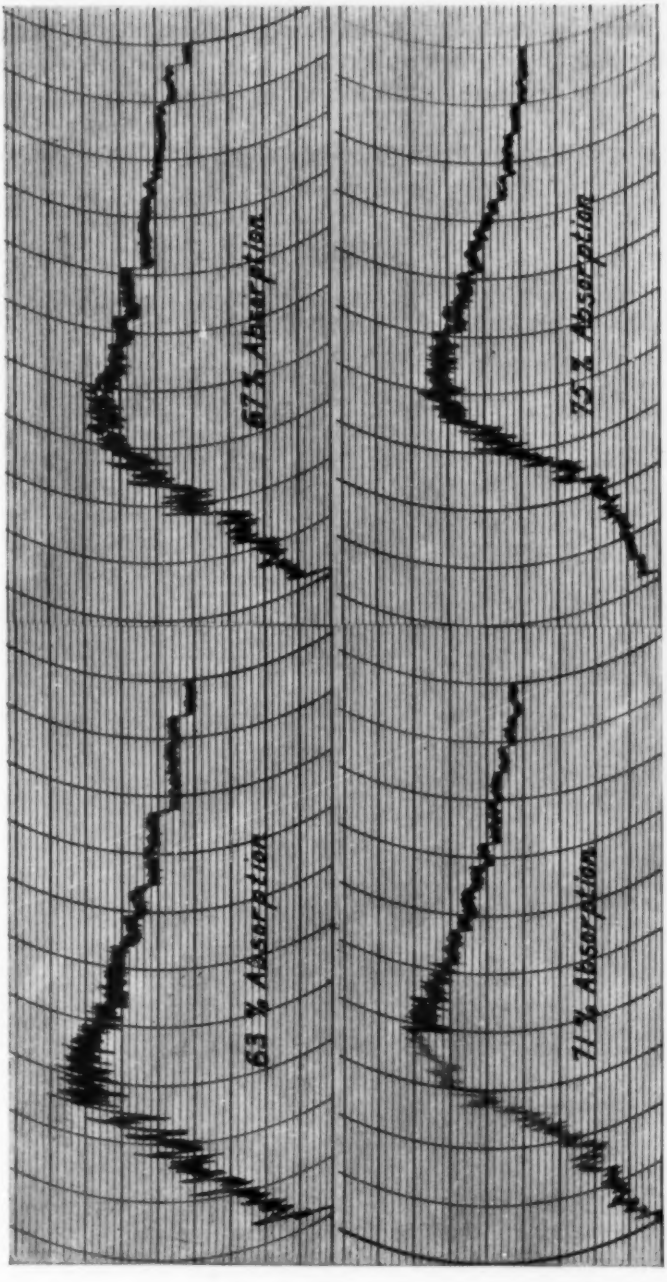

Fig. 18. Effect of varying absorption on type of curve.

measure of the rate of dough development. It is possible that temperature studies in connection with mixing may yield useful results. To test the influence of temperature on the character of the curve, doughs were prepared with water at 18° C., 25° C., and 30° C. and the resulting curves are illustrated in Figure 19. The temperature of the

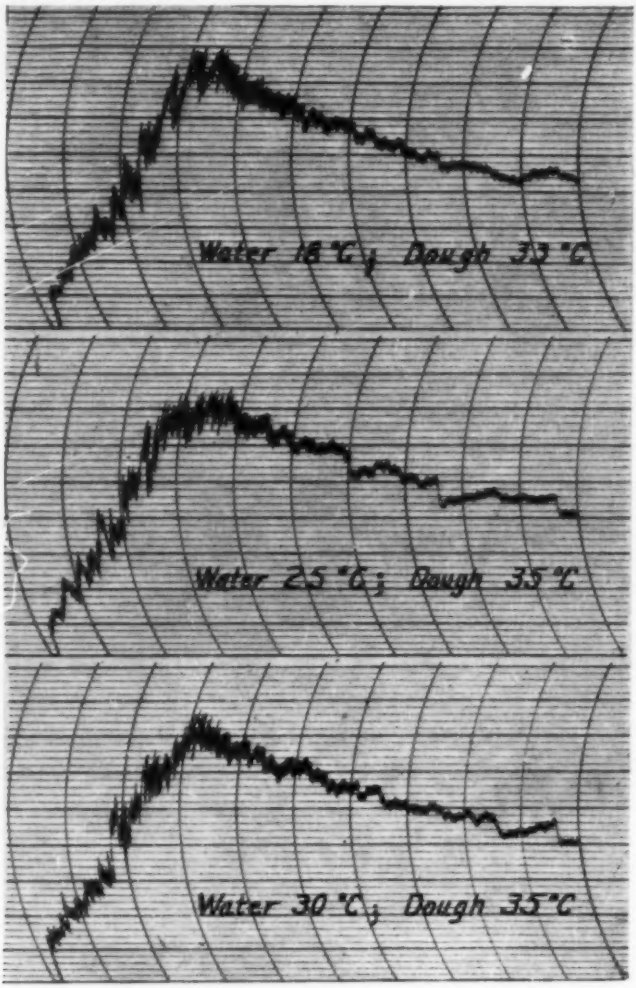

Fig. 19. Effect of varying the water temperature on type of curve.

room was 26° C. and the flour 25° C. A difference of 12° C. in the water used in preparing the dough made a difference of only 2° C. in the temperature of the dough at the end of the mixing time. The minor differences in curve characteristics indicate that small changes in temperature are of no serious consequence. However, until further

experiments are conducted along this line it is probably best to conduct all comparative tests at a uniform temperature.

To secure information relative to the effect of milling operations, or the blending of the flour streams, upon the characteristics of the curves, four curves were made respectively from the first break flour, fourth or last break flour, first middlings flour, and fifth middlings flour (Figure 20). The absorption percentages of these flours were respectively 57%, 66.5%, 60.3%, and 72.5%. These streams were from the same wheat used in milling the flour used in making the curves illustrated in Figure 17. The curves show the same medium steep upward slant and sharp turn in all but the fifth middlings flour. The most complete breaking down occurs in the first break flour, and the least in the fifth middlings. The dough from the first break flour was a sticky paste at the end of 7 minutes, while the other doughs were fairly stiff at the end of the 10 minutes. The height of the fourth break curve is very unusual. The curves on these mill stream flours suggest a possible use of this method in mill control, in that information relative to the streams contributing weaknesses in blended flours may be secured. It may be that the undesirable characteristics in some flours may be traced to substances which come from the bran.

The greatest possibilities with this recording dough mixer are probably in connection with the testing of wheat varieties. It was noted in connection with the use of the wattmeter that flours from certain varieties always gave characteristic curves. This discovery was the major stimulating factor in the construction of the recording dough mixer. Curves recorded from doughs of four varieties are illustrated in Figure 21. Flours milled from Blackhull and Early Blackhull varieties gave curves of very steep upward slopes, aburpt turns, and the breaking of the dough begins very soon after maximum development. The curve from flours milled from Turkey wheat has a much less abrupt slope, a more rounded turn, and, of particular interest, no such breaking down as occurs with Blackhull takes place. The Tenmarq curve is even more sloping than that of Turkey and even less breaking down of the dough is indicated. These characteristic varietal curves seem to be very closely related to the genetic factors. No matter where a Blackhull wheat is grown it gives the same type curve, as do also Turkey and Tenmarq regardless of soil and season. The constancy of such characteristics will be of great help in evaluating the qualities of new wheat varieties in comparison with the old and tested varieties.

It will be necessary to obtain curves of a considerable number of flours from different wheat classes in order to establish the correlation between curve characteristics and baking qualities. A beginning in

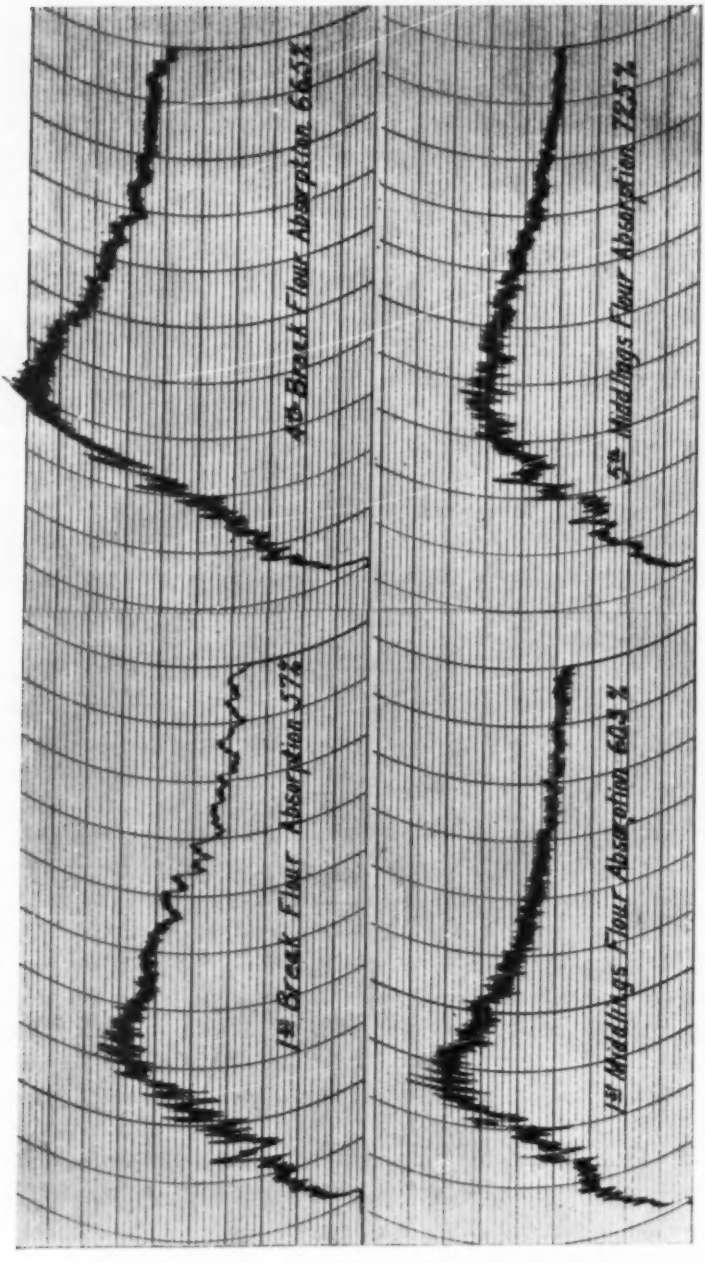
1st Break Flour Absorption 57%
4th Break Flour Absorption 66.5%
1st Middlings Flour Absorption 60.5%
5th Middlings Flour Absorption 72.5%

Fig. 20. Curves from 4 mill-stream flours.

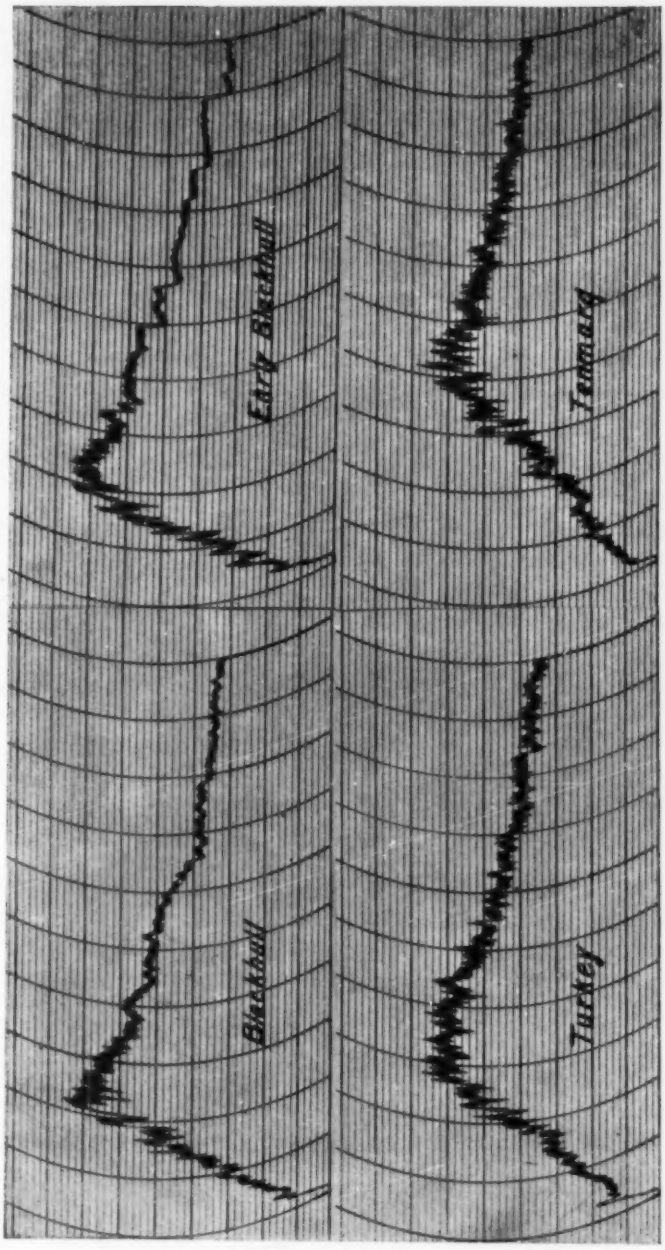

Fig. 21. Curves from flour of 4 varieties of wheat.

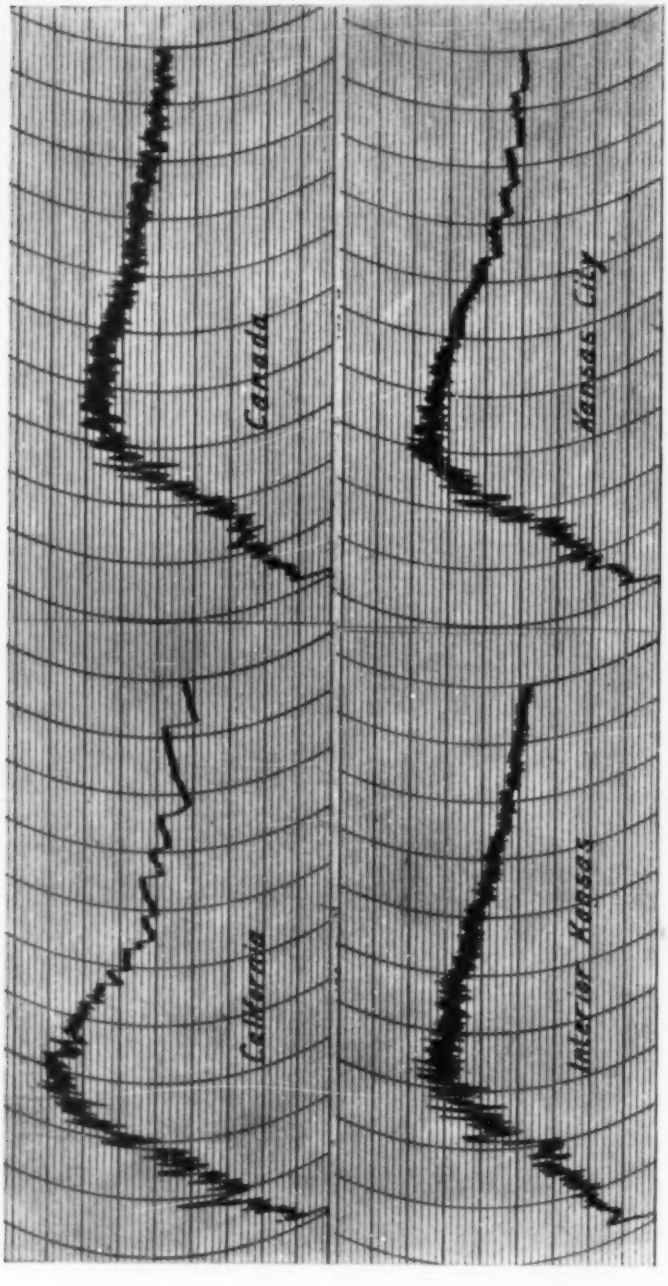

Fig. 22. Curves from 4 commercial flours.

this direction has been made by obtaining some 20 flours from representative mills in the United States and Canada. Typical curves representing flours from four different sources are illustrated in Figure 22. The California flour is probably made from a mixture of white and hard red wheats. The dough breaks soon after maximum development. The larger and more abrupt bends in the curve toward the end results from the development of stickiness in the dough causing it to adhere to the bottom of the bowl. The flour from Kansas City shows gradual development, and the dough resists breaking down for nearly 2 minutes after maximum development. However, since there is a complete breaking down in $6\frac{1}{2}$ minutes, the wheat mixture probably contained a considerable proportion of the variety Blackhull.

The Canadian flour is representative of very strong high protein flour. The rate of dough development is not unusual, but the rate of breaking down, which apparently begins at the end of 7 minutes, is so slow that comparatively little has occurred at the end of the mixing period. This curve may be considered as typical of a very strong hard spring wheat flour. The curve from the interior Kansas mill is very similar to the Canadian, but with somewhat more breaking down of the dough. This curve may be considered as typical of a strong hard winter wheat flour.

From these results it appears that this method may be valuable in checking variations in wheat mixtures if the characteristics of the classes and varieties are known. As far as our studies have gone the method will probably not detect slight damage in wheat. It may be that continued use of the machine on the same general wheat mixture would enable the operator to detect the introduction of damaged wheat.

It is realized that much experimentation must be done before a proper interpretation can be placed on results obtained with this apparatus. However, from the limited amount of work which has been done, it appears to be an instrument very valuable for fruitful investigation.

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SOME ASPECTS OF THE BROMATE BAKING TEST [1]

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Introduction

In recent years a considerable amount of data have been accumulated as a result of the application of the basic and bromate formulas to a wide range of wheat flours. Some of these researches have appeared in papers dealing with various phases of wheat and flour chemistry, but no specific comparison of the two formulas has been attempted recently. It, therefore, seemed of interest to collect in concise form some of the more important data in the published work and in our laboratory files which have a bearing on our present knowledge and interpretation of the bromate formula.

The use of small dosages of potassium bromate was brought actively to the attention of cereal chemists in America by Herman's (1927) description of a differential test (originated by Werner) in which the flour was baked by a simple formula consisting of flour, water, yeast, sugar, and salt only, and a formula consisting of the same quantities of these ingredients with the addition of 0.5% of Arkady or 0.001% of potassium bromate. The differences in baking results by these two methods were to be used in determining the characteristics of the flour in question. Blish and Sandstedt (1927) discussed the use of this bromate formula and stated that "flour showing the greatest stimulation in the differential test may be regarded as the least susceptible to over-treatment by the miller and vice versa." They pointed out further that the degree of stimulation is roughly proportional to the protein content, a relation which may constitute the foundation for the practice of paying premiums for high protein wheat.

Herman (1927) stated that "flours from the experimental mill giving positive reaction (to the differential baking test) are the product of wheats desirable for the commercial milling of so-called bread flours." Werner and Herman (1928) discussing interpretation of this test made the statement "it may generally be stated that flours non-responsive to the plus test (formula with bromate or Arkady) will be

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found lacking under commercial usage in, what is termed by the practical baker, strength or stability. As a rule they will not respond well to yeast foods or to severe treatment."

Thus in 1927 the general opinion of those who had experience with this test seemed to be that when used in conjunction with the basic standard test, the response observed furnished valuable evidence of the tolerance or instability of the flour toward treatment by oxidizing agents, but the basic formula was apparently still considered the standard for determining the comparative baking quality of flours by cereal chemists at large.

However, the following year Blish (1928), acting as Chairman of the A. A. C. C. Standard Experimental Baking Test Committee, emphasized that the basic procedure was merely a foundation and reference point, as pointed out by Werner (1925), and recommended several supplementary tests, including Supplement C involving additions of specified increments of potassium bromate to the formula. In discussing Supplement C mention was made of its value, not only as a test of tolerance toward oxidizing agents, but also for the estimation of flour strength depending on gluten quality. Heald (1929), acting on the Baking Test Committee, reported that the tests made with this supplement could not be related to other optional methods.

Larmour and MacLeod (1929) made a study of the application of the bromate differential test using, for the most part, experimentally milled Canadian hard red spring wheat flours and concluded that the bromate formula by itself gave a better measure of baking value than the basic formula. They observed that, although flours from high protein hard wheats usually gave positive responses, there appeared to be flours that were already fully matured which gave no response either negative or positive to the bromate test. On the basis of their observations they stated that flours might be divided into three classes: (1) Those giving negative response, which indicated weakness either inherent or due to damage; (2) those giving marked positive responses, which indicated high strength; and (3) flours giving no appreciable response, which usually indicated optimum development of the flour. Well developed commercial Canadian flours usually fall into the last class, giving high loaf volume by the basic formula and showing neutral response to the addition of 0.001% potassium bromate.

Moen (1930), acting as a member of the Baking Test Committee of the A. A. C. C., reported that experiments with the bromate test indicated that magnitude of response to bromate has no connection with fermentation tolerance of the dough, but appears to be closely related to its ability to stand up against dosages of improvers and yeast nutrients commonly used in the bake shop.

Before proceeding further with the discussion it might be well to consider the difference between commercial flour testing and wheat testing, a distinction which was emphasized by Larmour and MacLeod (1929a). In mill control work the material consists for the most part of finished flours which are usually processed in such a manner as to bring them close to their optimum development. Commercial flour testing thus resolves itself largely into applying a baking method which will reveal whether or not the flour comes up to certain fairly well defined standards.

The testing of wheat quality, however, presents a different and more difficult problem, particularly in the instance of Western Canadian wheats. In this instance an attempt must be made to measure the potentialities of a raw material which, in commercial practice, is almost invariably mixed for domestic consumption with other lots of hard red spring wheat, or blended with a wide variety of softer wheats, if sold on the foreign market. Furthermore, the resulting flours are baked under widely varying conditions with regard to baking formulas, methods of mixing, and fermentation time. Finally, the character of the loaf desired differs according to country and locality. The testing of specific wheat samples is thus more involved than estimating the performance of a finished commercial commodity and this difference should be kept in mind because most of the data hereinafter presented were obtained on flours experimentally milled from individual wheat samples and not from commercial mixtures.

In connection with the various projects undertaken in their laboratories, the authors have had occasion to test large numbers of wheat samples grown in different years and varying in protein content and soundness, and some of the data condensed from previous publications or compiled from our laboratory files are included to facilitate further discussion.

Application of Different Baking Formulas to Flours Milled from Sound Wheat

Application of the basic formula of the A. A. C. C. to the evaluation of the strength of Canadian hard red spring wheat has been found to give results which, considered by themselves, would lead to preposterous deductions. For instance, high protein samples from the Southwest of Saskatchewan, a district reputed for its production of high quality wheat, gave lower loaf volumes than low protein samples grown three hundred miles further north, in the wooded area—a result completely at variance with the generally accepted evaluation.

Referring to Table I, it is seen that sample No. 22 with 13.9% of protein gave a loaf volume of 650 cc., while No. 24 with 18.7% of

protein gave 640 cc. When these flour samples were baked with bromate the values increased to 730 cc. and 890 cc., respectively. All of these samples respond to 0.001% $KBrO_3$ with a very large

TABLE I

POSITIVE RESPONSE OF STRAIGHT GRADE FLOURS EXPERIMENTALLY MILLED FROM SOUND WESTERN CANADIAN MARQUIS WHEAT TO ADDITION OF 0.001% OF POTASSIUM BROMATE

Crop year	Sample number	Protein of wheat [1]	Loaf volume		Response to bromate
			Basic formula	Bromate formula	
		P.ct.	cc.	cc.	cc.
1926	1	12.4	514	600	86
	2	16.2	474	610	136
	3	17.2	492	662	170
	4	17.4	564	700	136
1927	5	12.3	540	624	84
	6	12.9	532	600	68
	7	14.0	566	710	144
	8	14.0	508	636	128
	9	15.6	550	660	110
1928	10	13.0	547	632	85
	11	13.4	550	660	110
	12	14.2	601	742	141
	13	14.4	580	703	123
	14	15.2	595	722	127
1929	15	11.9	477	640	163
	16	12.7	578	728	150
	17	14.3	575	815	240
	18	16.1	590	818	228
	19	17.9	615	938	323
1930	20	11.6	565	625	60
	21	12.9	533	692	159
	22	13.9	650	730	80
	23	16.9	635	760	125
	24	19.0	640	890	250
1931	25	12.0	650	740	90
	26	14.3	620	785	165
	27	14.8	645	820	175
	28	14.6	665	920	255
	29	15.0	740	840	100
	30	15.9	665	940	275

[1] 13.5% moisture basis.

increase in loaf volume, and the results by this formula enable one to place the samples, at least for any given crop year, into relative positions which are more in line with their commercial evaluation.

Not all Western Canadian wheats react in this manner to $KBrO_3$. In Table II there are shown a number of samples from each of the

crops 1926 to 1931 inclusive, which gave neutral or negative responses. It should be observed that, on the whole, these flours were lower in protein than those listed in Table I. There are, however, a number which were high in protein and gave high loaf volume by the basic method but showed no effect from the bromate. For instance,

TABLE II

NEUTRAL OR NEGATIVE RESPONSE OF STRAIGHT GRADE FLOURS EXPERIMENTALLY MILLED FROM SOUND WESTERN CANADIAN MARQUIS WHEAT TO ADDITION OF 0.001% OF POTASSIUM BROMATE

Crop year	Sample number	Protein of wheat [1]	Loaf volume		Response to bromate
			Basic formula	Bromate formula	
		P.ct.	cc.	cc.	cc.
1926	1	12.6	606	600	−6
	2	13.1	540	538	−2
	3	11.2	600	600	0
	4	11.2	596	590	−6
	5	11.7	604	620	16
1927	6	11.4	594	594	0
	7	11.9	624	640	16
	8	12.3	616	600	−16
	9	14.0	604	610	6
	10	8.8	533	532	−1
	11	9.3	447	460	13
1928	12	10.8	556	551	−5
	13	11.1	563	537	−26
	14	11.6	555	570	15
	15	8.8	472	460	−12
	16	9.6	565	570	−5
1929	17	10.0	540	530	−10
	18	10.8	575	580	5
	19	14.2	770	763	−7
	20	11.2	530	548	18
	21	12.4	650	650	0
1930	22	14.0	795	773	−22
	23	14.2	740	730	−10
	24	15.4	783	735	−48
	25	16.6	930	900	−30
1931	26 [2]	13.3	655	620	−35

[1] 13.5% moisture basis.
[2] Garnet sample.

sample No. 19 gave 770 cc. loaf volume by the basic formula, and 763 cc. loaf volume by the bromate formula. Evidently this sample possessed some particular character, by virtue of which a good or perhaps a maximum loaf could be produced by the simple basic formula. The experimentally milled sample of flour appeared to be perfectly

developed. Samples Nos. 22, 23, and 24 were similar to No. 19 in this respect.

It is obvious from these data that samples of wheat differ, some giving flour that appears quite developed, others giving flour that does not behave properly by the basic formula, appearing "gluten-bound" and "harsh." Generally low protein wheats fall in the former class and high protein wheats in the latter, but there are a number of exceptions.

A large positive response to bromate usually indicates a strong flour but this does not hold strictly for all cases. For example, in Table I sample No. 15 containing 11.9% of protein gave a response of 163 cc. in loaf volume. This is a very large increase, but when it is considered that this merely brought the volume to 640 cc. it cannot be concluded that this was a very strong sample of flour. Sample No. 22 in Table II, showing no response, but having a volume of 773 cc. by the bromate formula, should be judged the stronger. Larmour and MacLeod (1929) stated that "flours that give a marked positive response to bromate must be considered strong and those that give a negative response must be considered weak," but evidently this statement was too broad. In considering the reaction to bromate, apparently one must take into account both the basic and bromate volumes as well as the kind and magnitude of response, because it appears quite obvious that a flour of very low basic volume might exhibit a marked positive response to attain a bromate volume very much less than another flour that had a high basic volume and which gave a negative response. The limitations of the basic formula in estimating wheat strength and the necessity of considering the basic and bromate volumes independently of the bromate response is clearly illustrated in Tables III and IV. Referring to Table III, the series of samples listed, ranging in protein content from 9.6% to 18.4%, would be judged of equal strength by the basic formula. On the other hand, the bromate values reveal wide differences in strength as shown by a range in loaf volume from 570 to 830 cc. Moreover, the bromate results show a progressive increase in strength with increasing protein content and are fairly consistent with the relative order of value revealed by the blend-bromate formula which has been shown by Larmour and MacLeod (1929a) to give a measure of strength quite in line with commercial experience. In this series the magnitude of the bromate response increases with the protein content and is positively correlated with strength.

Samples of the same protein content grown in the same crop year may, however, show very wide differences in their response to bromate. This appears to be due mainly to the differences obtained with the basic

formula. Data on a small series of such samples are given in Table IV. These gave very wide variations in the basic test, the range being 235 cc., whereas by the bromate test they were practically all of the

TABLE III

LOAF VOLUMES GIVEN BY SOUND SAMPLES OF WHEAT OF DIFFERENT PROTEIN CONTENT, GROWN IN THE SAME CROP YEAR: SAME LOAF VOLUMES BY THE BASIC FORMULA BUT DIFFERENT LOAF VOLUMES BY THE BROMATE FORMULA

Wheat protein [1]	Loaf volume			
	Basic formula	Bromate formula	Response	Blend-bromate [2]
P.ct.	cc.	cc.	cc.	cc.
9.6	565	570	5	540
10.0	560	608	48	555
10.5	570	585	15	563
11.4	560	608	48	570
11.7	570	635	65	570
12.3	560	640	80	555
12.5	565	660	95	555
13.3	570	712	142	603
13.6	560	748	188	610
14.0	565	735	170	592
14.4	570	745	175	545
15.1	570	760	190	640
15.9	565	835	270	678
16.4	570	875	305	688
16.9	567	755	188	695
17.4	565	805	240	750
18.4	555	830	275	670

[1] 13.5% moisture basis.
[2] 50–50 blend with Pacific Club wheat flour, 6.7% protein

same volume, the range being only 12 cc. Judged by the basic data, these samples would be arranged in descending order of baking quality as in the table, but judged on the responses the order would be completely reversed. By the bromate formula they would be considered of equal value and this would seem to be the correct deduction, in view of the fact that they showed practically no differences when baked in a 50–50 blend with soft flour.

Thus it appears that although responses to bromate are useful when applied to the evaluation of finished flour and also to special studies in which a good estimate of the inherent quality of the flour has been previously obtained, as in the heat treatment studies by Geddes (1929), when used with experimental flours from high protein hard wheats, they may lead to altogether erroneous conclusions. It would seem, furthermore, that with this class of material, the basic test is of little value unless it be to estimate the extent to which the flour may be considered "gluten-bound." As a single test designed to give an approximate idea of the capability of such flours, the bromate is to

be recommended before the basic method. This view receives confirmation in the relation found by Larmour (1931) between wheat protein and loaf volume. The correlations obtained between these variables on 665 samples were $r = +0.630 \pm .016$, $r = +0.906 \pm .005$,

TABLE IV

LOAF VOLUMES GIVEN BY SOUND SAMPLES OF WHEAT OF APPROXIMATELY THE SAME PROTEIN CONTENT: APPROXIMATELY EQUAL LOAF VOLUMES BY THE BROMATE FORMULA BUT DIFFERENT LOAF VOLUMES WITH THE BASIC FORMULA

Sample number	Wheat protein [1]	Loaf volume		Response	Blend bromate [2]
		Basic	Bromate		
	P.ct.	cc.	cc.	cc.	cc.
1	14.2	770	763	−7	615
2	14.5	730	772	42	615
3	14.2	640	770	130	610
4	14.7	640	773	133	598
5	14.2	625	775	150	625
6	14.3	610	770	160	595
7	14.8	595	770	175	600
8	14.0	560	775	215	600
9	14.6	535	775	240	605

[1] 13.5% moisture basis.
[2] 50–50 blend with Pacific Club flour of 6.7% protein content.

and $r = +0.838 \pm .008$ for the basic, bromate, and blend-bromate volumes respectively. The fraction of the total variance independent of protein content was 60% for the basic, 18% for the bromate, and 30% for the blend-bromate, and hence the bromate and blend-bromate data justify the commercial importance attached to protein as a measure of strength. Larmour also found, from a study of the regressions of loaf volume on protein that the blend bromate formula was effective in estimating relative strength over the whole range of protein (7.0% to 19.3%), while the bromate formula gave a linear regression of 15.9% and the basic formula to 14.9% protein. While the bromate formula failed in the higher protein classes it must be borne in mind that only 0.001% $KBrO_3$ was used throughout and it will be shown later that this quantity is insufficient in the instance of unaged and unbleached flours of high protein content to reveal their maximum loaf volumes. Further evidence of the soundness of our views regarding the relative value of basic and bromate baking tests and the interpretation of bromate response is to be found in the application of these formulas to studies on the effect of damage on wheat and flour strength (such as heat, and the presence of frosted, sprouted or otherwise damaged kernels) and the influence of natural and artificial aging.

TABLE V

THE EFFECT OF HEAT TREATMENT ON STRAIGHT GRADE FLOUR

Summary of loaf volumes and physico-chemical and chemical determinations related to baking quality

Heat treatment		Loaf volume				Viscosity	Per cent of total protein peptized by $N/_1MgSO_4$	Maximum gas retention	Water imbibed per gram dry gluten in 140 minutes	Diastatic activity (Rumsey units)
Temperature	Time	Basic formula	Bromate formula	Malt-bromate formula	Response to bromate					
° F.	hours	cc.	cc.	cc.	cc.	degrees [1]	P.ct.	cc.	gm.	
Control		560	635	672	75	182	18.8	106	6.93	219
130	8	545	589	605	44	173	17.5	82	6.64	211
135	8	552	585	604	33	161	17.0	84	6.29	213
140	8	563	554	577	−9	154	16.7	80	6.16	216
160	0.5	533	611	590	78	166	15.8	102	6.78	213
160	1	515	541	542	26	150	15.7	90	—	213
160	2	521	486	479	−35	133	15.3	71	6.82	204
160	3	479	422	404	−57	105	14.9	60	4.21	200
160	4	414	325	338	−87	93	14.4	61	—	203
160	6	352	283	306	−69	67	13.9	55	—	180

[1] Wallace and Tiernan viscosimeter.

Heat Treatment Studies

Geddes (1929) applied the basic and bromate formulas to an unbleached straight grade flour commercially milled from Western Canadian hard red spring wheat which had been subjected to a series of heat treatments. A portion of the baking data with certain physico-chemical and chemical studies conducted on these flours and reported in a subsequent paper (Geddes 1930) are reproduced in Table V.

Baking strength, as revealed by the basic loaf volumes, showed progressive improvement as the temperature or time of heating was extended within a certain range, beyond which marked damage resulted. The bromate volumes, however, revealed damage to baking quality with all heat treatments, and the bromate response decreased with increasing severity of the treatment. In the series of samples listed in Table V, the basic volumes range from 352 cc. to 560 cc., and the bromate from 283 cc. to 635 cc. The bromate formula thus appears to be much more sensitive than the basic in indicating modifications in flour strength as a result of heat treatment. In this series the protein content is identical, heat treatment resulting in an impairment of gluten quality. This is evidenced by, (1) a marked and progressive decrease in viscosity of the leached and acidulated flour suspensions; (2) a lesser peptization of the flour proteins; (3) a decrease in the gas retaining capacity of the doughs; and (4) a lower hydration of the washed out gluten.

In view of this evidence of progressively decreasing gluten strength, as a result of heat treatment, it is of interest to examine the correlations between these measures of gluten quality and the loaf volumes obtained by the different baking formulae. The values given in Table VI indicate that the use of bromate gives a somewhat better measure

TABLE VI

SIMPLE CORRELATIONS BETWEEN LOAF VOLUME AND VARIOUS MEASURES OF GLUTEN QUALITY

Correlations between	Basic formula	Bromate formula	Malt-bromate formula
Loaf volume and viscosity	$+0.980 \pm .006$	$+0.989 \pm .003$	$+0.980 \pm .006$
Loaf volume and per cent of protein peptized	$+0.938 \pm .017$	$+0.952 \pm .014$	$+0.957 \pm .012$
Loaf volume and maximum gas retention of dough	$+0.866 \pm .037$	$+0.947 \pm .015$	$+0.942 \pm .017$

of the relative strength of these flours than the basic formula. It is important to note, in this connection, that the failure of the heat treated flours to yield satisfactory loaf volumes is not overcome by the use of diastatic malt and hence must be ascribed chiefly to alterations

TABLE VII

INFLUENCE OF DRYING WHEAT WITH CONTINUOUS GRAIN DISCHARGE AT VARIOUS AIR FLOWS AND TEMPERATURES ON LOAF VOLUME AS DETERMINED BY THE BASIC AND BROMATE FORMULAS

Moisture in wheat		Total time in heater section	Hot air flow		Air temperature heater section		Maximum grain temperature	Loaf volume as per cent of check	
Original	Final		Per pound grain	Per minute	Inlet	Outlet		Basic formula	Bromate formula
P.ct.	P.ct.	min.	lbs.	lbs.	° F.	° F.	° F.	P.ct.	P.ct.
19.1	14.3	64	3.8	1.9	242	88	131	99	87
19.3	14.2	50	3.3	2.4	239	91	136	102	91
19.2	14.5	34	3.4	3.7	240	89	140	97	81
19.3	13.8	28	3.8	4.8	242	92	160	91	68
18.3	13.2	26	4.4	6.3	241	95	168	93	68

in gluten quality and not to heat inactivation of diastase. The greater range in loaf volume and the closer relation between volume and strength by the use of the bromate formula would appear to render it particularly suitable to an experimental study of proper conditions (such as air flow, air temperature, etc.) for the safe drying of tough and damp wheat. Stansfield and Cook (1932) have recently reported the results of extensive studies in this field and a few comparative loaf volumes by the basic and bromate formulas, expressed as a percentage of the corresponding check sample, are given in Table VII for one series of experiments.

In the instance of the first three samples, the basic formula indicates that the drying conditions had no appreciable effect on loaf volume, while the last two samples show slight damage. The bromate formula, on the other hand, shows that all samples were damaged, the last two in particular. The range in this series is 11% for the basic and 23% for the bromate formula. The latter formula is thus more sensitive as a measure of changes in wheat quality as a result of artificial drying.

Frosted Wheat

Larmour and MacLeod (1929) and Geddes, Malloch and Larmour (1932) have published data for several baking formulas obtained on samples representative of the Western Canadian red spring wheat crop of 1928. In that year, owing to a limited rainfall following germination, combined with late heavy frosts, a large portion of the wheat marketed contained many types of frost damage together with immature and green kernels, and a comparison of the mean loaf volumes obtained by the basic and bromate formulas for the different grades is of considerable interest. The mean values for the physical classification of the kernels, protein content of wheat and loaf volumes for two flour extractions, together with responses to bromate, arranged according to wheat grade and compiled from the data of Geddes, Malloch and Larmour (1932) are given in Table VIII.

Considering the average wheat quality of the different grades, as expressed by the baking results with the basic formula, it would appear that the quality improves as the grade of wheat decreased to No. 5. Flours milled from badly frosted No. 6 wheat gave a higher mean loaf volume than sound wheat grading Nos. 1 and 2 Northern. On the other hand, the mean loaf volume by the bromate formula, with the exception of Grade No. 4, progressively decreased with a decrease in grade, or, in other words, with an increase in the mean percentage of damaged kernels present. These results, by the basic formula, are entirely incongruous with the commercial evaluation of the grades and

TABLE VIII

MEAN VALUES FOR PHYSICAL CLASSIFICATION OF WHEAT KERNELS,[1] PROTEIN CONTENT, LOAF VOLUME BY THE BASIC AND BROMATE FORMULAS, AND BROMATE RESPONSE, ARRANGED ACCORDING TO GRADE, FOR SAMPLES REPRESENTATIVE OF THE 1928 HARD RED SPRING WHEAT CROP OF WESTERN CANADA

Grade	Number of sample	Physical classification of kernels			Protein in wheat [2]	Mean loaf volume					
						55% Patent		Straight grade		Response to bromate [3]	
		Total sound	Bran frost	Heavy damage		Basic formula	Bromate formula	Basic formula	Bromate formula	55% patent	Straight
		P.ct.	P.ct.	P.ct.	P.ct.	cc.	cc.	cc.	cc.	cc.	cc.
1 & 2	52	85.5	1.9	9.4	12.2	519	556	508	552	41	46
3	38	74.2	5.3	16.8	11.8	523	542	506	534	24	25
4	51	58.6	15.9	21.1	12.1	537	560	528	557	21	30
5	48	30.8	28.8	36.0	12.0	538	540	527	516	−5	−7
6	39	18.6	28.5	48.5	12.3	528	494	515	477	−31	−34

[1] Compiled from the paper of Geddes, Malloch and Larmour (1932).
[2] 13.5% moisture basis.
[3] The baking data by both methods were not in all cases complete for the two flour extractions. The mean bromate response recorded was calculated only for the flours for which complete data were available.

are in agreement with the observations of Larmour and MacLeod (1929) that the basic baking procedure, when used with experimentally milled Canadian hard red spring wheat flours, cannot be wholly relied upon to give a true measure of the quality of such wheat. The flours milled from sound wheat gave, on the average, larger volumes when baked by the bromate formula, while those milled from badly frost-damaged wheat gave much lower volumes, with the result that the range in mean loaf volume for the different grades was greatly increased. For example, for the results obtained on the 55% patent flour, the range is 19 cc. and 66 cc. for the basic and bromate formulas respectively. It is worthy of mention that the patent and straight grade flours were milled and baked in different laboratories, and the baking results are in close relative agreement. The correlations between protein content of wheat and loaf volume were significantly higher for the bromate results, and there seems little doubt that the experimental baking results by this formula are more in line with the actual quality of the wheat.

In this series, the mean protein content was practically constant for the different grades of wheat, and, in general, the average response to bromate decreased with lowered wheat grade. The question again arises as to what interpretation is to be placed on these responses. In order to determine the relation between protein content, percentage of sound kernels and bromate response, the correlations given in Table IX have been calculated for the results obtained on the individual flours.

TABLE IX

CORRELATIONS INVOLVING RESPONSE TO BROMATE (STRAIGHT GRADE FLOUR)

	Simple correlation coefficients			Second order partial correlation coefficients for response to bromate
	Wheat protein [1]	Total sound	Bromate response	
	(6)	(1)	(B)	
Wheat protein (6)	—	—	+.319	$r_{6B.12} = +.469$
Total sound (1)	−.031	—	+.527	$r_{1B.62} = +.407$
Bran frost (2)	+.183	−.785	−.344	—
	At 5% point $r = .138$			At 5% point $r = .139$
Multiple correlation:	$R_{B(62)} = .625$; 5% point = .240			

[1] 13.5% moisture basis.

The correlations $r_{6B.12}$, showing the relation between wheat protein and bromate response when the percentage of total sound and bran frosted kernels are held constant, and $r_{1B.62}$, giving the relation between bromate response and percentage sound kernels with protein and bran frost constant, are both positive and significant. It seems logical

to presume that the inherent protein quality of frosted, green and immature kernels would be inferior to that of sound kernels, and if this assumption is made, the data indicate that bromate response is associated, in part, with "quality" and quantity of the protein. These correlations are, however, not sufficiently high to lead to the conclusion that the bromate response is always to be interpreted as a measure of the quantity or quality of the protein present. The rather low multiple correlation showing the combined effect of protein content and percentage of sound kernels is a reflection of the fact that many individual flours of high protein content milled from sound wheat gave low responses, and, on the other hand, some flours milled from the lower grade wheats gave good responses. It, therefore, seems unsafe

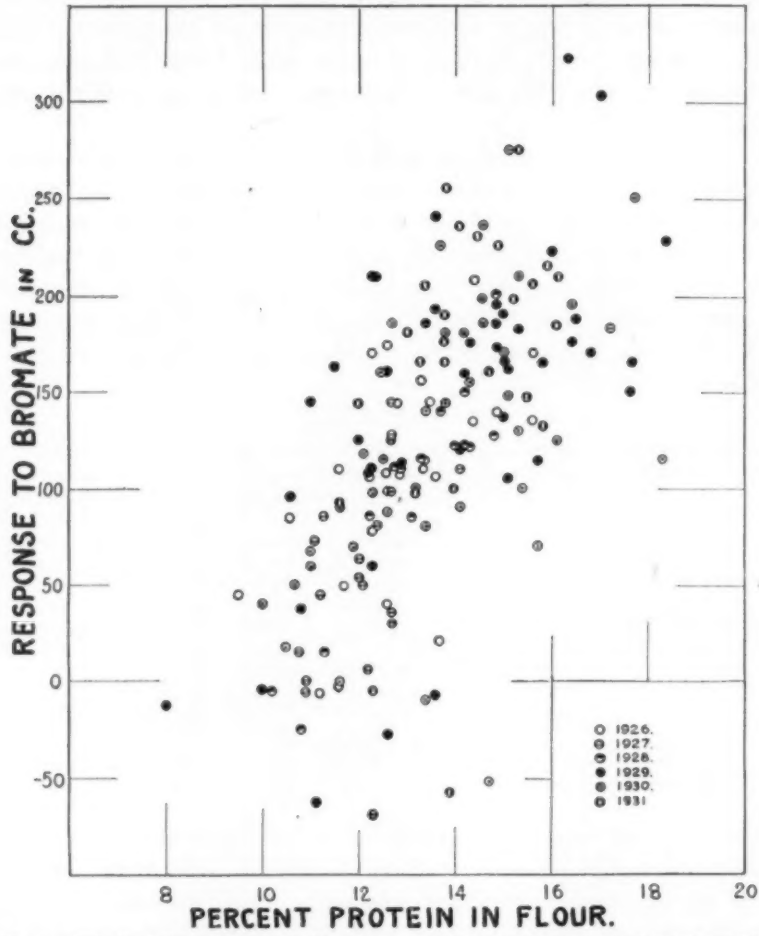

Fig. 1. Relation between flour protein and response in loaf volume obtained by the addition of 0.001% $KBrO_3$. Straight grade flours experimentally milled from sound Marquis wheat grown in the crop years 1926 to 1931 inclusive.

to conclude that a poor response to bromate in the instance of a particular flour is always an indication of inherent weakness.

At this point it seems convenient to introduce Figure 1 and Table X, showing the relation between protein content of flour, milled from sound Marquis wheat grown in the crop years 1926 to 1931 inclusive, and the response in loaf volume obtained by the addition of 0.001% $KBrO_3$. The correlations, while not high, are quite significant and indicate again that protein quantity is an important factor influencing bromate response.

TABLE X

CORRELATIONS BETWEEN FLOUR PROTEIN AND RESPONSE IN LOAF VOLUME OBTAINED BY ADDITION OF 0.001% $KBrO_3$

Crop year	Number of samples	r (Flour protein × bromate response)	Approximate value of r at 5% point
1926	25	+.571	.38
1927	21	+.472	.41
1928	16	+.928	.46
1929	45	+.630	.29
1930	40	+.633	.30
1931	24	+.335	.38
Entire series	171	+.633	.15

Sprouted Wheat

There is comparatively little information on our files regarding the comparative results obtained by the basic and bromate formulas on flours milled from sprouted wheat. However, a few typical results obtained in a study of the influence of weathering on wheat quality, conducted at Saskatoon in 1927, are given in Table XI.

TABLE XI

PROTEIN CONTENT AND LOAF VOLUME BY THE BASIC AND BROMATE FORMULAS OBTAINED ON FLOURS MILLED FROM SOUND VS. WEATHERED WHEAT GROWN AT SASKATOON IN 1927

Description of sample	Protein in wheat [1]	Loaf volume		Bromate response
		Basic formula	Bromate formula	
	P.ct.	cc.	cc.	cc.
Sound wheat, control sample	11.9	540	546	+6
Weathered wheat, contained 17% sprouted kernels	11.1	576	510	−66
Weathered wheat, contained sprouted kernels	11.8	580	522	−58
Weathered wheat, contained 13.5% sprouted kernels	12.4	680	580	−100
Weathered wheat, contained 17% sprouted kernels	12.5	615	526	−89
Weathered wheat, contained sprouted kernels	12.7	622	580	−42

[1] 13.5% moisture basis.

In this series, the basic formula indicates an improvement in wheat quality as a result of the presence of sprouted kernels, while the bromate formula reveals little change, with the result that the weathered samples give strong negative bromate responses, while the sound samples show practically no response.

It will be shown later that bromate affects the gas retaining capacity of doughs, but has no measurable influence on the rate of gas production, and hence the different baking behavior of the sound and weathered samples in regard to bromate response cannot be attributed to the higher diastatic activity of the latter. It has been our general experience that baking results by the basic formula are influenced by variations in enzymic activity to a much greater extent than by the bromate. While diastatic activity may be in part responsible for the increased volumes shown by the basic formula as a result of weathering, the negative responses to bromate may be considered as an indication of a modification of the colloidal character of the gluten of these flours, probably as a result of proteolytic activity, so that the basic formula gives loaf volumes more nearly approaching the maximum capability of these flours.

Aging and Bleaching Studies

It is well known that the storage of unbleached flour results in a decrease in carotin content coupled with a progressive improvement in apparent strength to a fairly definite optimum. On further storage the strength gradually diminishes and the flour becomes more susceptible to overfermentation. There is, however, comparatively little published data regarding the effect of natural aging on the behaviour of flours toward potassium bromate.

In order to procure information on this point, a series of six flours from each of the crop years 1928 and 1929 that had been stored in the laboratory in air-tight containers were rebaked by the basic and bromate (0.001%) formulas. The 1928 flours had been in storage 35 months, and the 1929 flours 23 months, since they were first baked. While it must be admitted that some of the changes observed may have been due to differences in baking technique, there is reason to believe that the error due to this cause was relatively small for, in another study, some wheats of the 1927 crop were remilled and baked late in 1931 and the results compared to those obtained with the original baking. The agreement was, on the whole, very good, as can be seen from Table XII. It can be concluded, therefore, that, for the most part, the differences shown in Table XIII were due to changes occurring in the flours as a result of aging. In general, loaf volume by both the basic and bromate formulas decreased but the decline was greater in

the case of the bromate formula, with the result that the response of the aged flour was, in most cases, very much less than the response of the newly milled flours. This may be interpreted to mean either that

TABLE XII

COMPARISON OF BAKINGS MADE AT DIFFERENT TIMES ON FRESHLY MILLED FLOURS

Sample number	First milling and baking			Second milling and baking		
	Date milled	Date baked	Loaf volume	Date milled	Date baked	Loaf volume
			cc.			cc.
1	May 1931	June 1931	670	Aug. 1931	Oct. 1931	683
2	May 1931	June 1931	653	Aug. 1931	Oct. 1931	670
3	May 1931	June 1931	575	Aug. 1931	Oct. 1931	570
4	Jan. 1930	Mar. 1930	605	Aug. 1931	Oct. 1931	620
5	Jan. 1930	Mar. 1930	727	Aug. 1931	Oct. 1931	758
6	Jan. 1930	Mar. 1930	763	Aug. 1931	Oct. 1931	760
7	Apr. 1929	May 1929	551	Aug. 1931	Oct. 1931	548
8	Apr. 1929	May 1929	502	Aug. 1931	Oct. 1931	485
9	Apr. 1929	May 1929	632	Aug. 1931	Oct. 1931	632
10	Dec. 1928	Jan. 1929	730	Aug. 1931	Oct. 1931	718
11	Dec. 1928	Jan. 1929	660	Aug. 1931	Oct. 1931	688
12	Dec. 1928	Jan. 1929	636	Aug. 1931	Oct. 1931	610

the character of the proteins had changed or that some intermediate on which the bromate acts, had altered during storage. From the data it appears that probably both changes occurred because there was a decrease in volume as well as in response.

It should be pointed out that these data do not agree with those of Saunders, Nichols, and Cowan (1922) which showed an improvement in volume after three years storage. The whole question of flour aging needs further investigation and is being undertaken as a separate study.

Turning now to chemical bleaching it has been noted by several workers that maturation of flour with oxidizing agents, such as nitrogen trichloride and chlorine, reduces the response to bromate, indicating that bromate plays somewhat the same role as bleaching. This suggests that the bromate response of an unbleached flour would serve as an indication of the reaction to be expected from bleaching, thus providing a ready means for comparing flours in respect to this property.

Larmour and Machon (1931) have recently reported the results of their studies conducted, in part, with this object in mind. Straight grade flours experimentally milled from samples of pure strain Marquis wheat of varying protein content were each bleached with increasing dosages of Beta Chlora and Novadel. These samples were baked the

TABLE XIII

THE EFFECT OF NATURAL AGING ON LOAF VOLUME AND BROMATE RESPONSE

Sample number	Protein of wheat [1]	Loaf volume of newly milled sample		Response to bromate	Loaf volume after 23 months storage		Response to bromate	Changes in loaf volume due to aging		
		Basic formula	Bromate formula		Basic formula	Bromate formula		Basic formula	Bromate formula	Response
	P.ct.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.
				Flours Milled from 1929 Crop						
1	11.2	520	590	70	503	593	90	−17	+3	+20
2	12.3	555	700	145	543	595	52	−12	−105	−93
3	12.5	595	715	120	580	603	23	−15	−112	−97
4	13.5	505	715	210	443	548	105	−62	−167	−105
5	14.0	565	735	170	468	528	60	−97	−207	−110
6	14.5	560	778	218	465	608	143	−95	−107	−75
				Flours Milled from 1928 Crop						
1	11.3	519	607	88	525	553	28	+6	−54	−34
2	11.4	605	600	−5	550	563	13	−55	−37	+18
3	12.3	577	653	76	495	553	58	−82	−100	−18
4	13.4	580	702	122	475	510	35	−70	−192	−87
5	13.6	558	698	140	460	515	55	−98	−183	−85
6	14.1	665	758	93	550	553	3	−115	−205	−90

[1] 13.5% moisture basis.

day after bleaching by the basic and bromate formulas and again after one month's storage. Since Novadel produced no maturing effect their results with Beta Chlora only will be considered. From a portion of the data reproduced in Table XIV it will be noted that, with respect to apparent strength as revealed by the basic volumes 24 hours after bleaching, the reaction to Beta Chlora is directly related to protein content. The low protein flour showed no beneficial result, while the higher protein flour exhibited responses to progressively increasing dosages of chlorine. It will be recalled that the response to bromate is also conditioned by the protein content, but there is additional evidence in these data to indicate that its action is similar to that of maturing agents. As the quantity of bleach is increased there is a definite trend towards decreased bromate response. Furthermore, when the bromate volumes of the unbleached sample are compared with the largest basic volume on the corresponding sub-sample there is fairly close agreement. This suggests that the data obtained by application of the bromate formula to unbleached, freshly milled flours would, in general, be indicative of the results to be expected from flours fully matured by artificial means and baked without the addition of bromate.

It will be noted also that the response of the flours to natural aging increases with the protein content, but is reduced by superimposing additional oxidizing effects on the flour, either in the form of potassium bromate or increasing increments of Beta Chlora.

A point of particular importance is that the corresponding bleached and unbleached samples gave practically identical volumes when baked by the blend formula—a formula which Larmour (1931) has shown, gives an accurate measure of the relative strength of hard red spring wheat flours. The actual strength of the unbleached and corresponding bleached samples must thus be regarded as identical.

On the basis of these studies we are led to the conclusion that any particular flour has a definite inherent strength which is conditioned largely by its protein content. Freshly milled unbleached flours of high protein content fail to reveal their maximum capabilities when baked by the basic formula, but may be brought in the direction of their optimum by natural aging, artificial maturation or the addition of bromate to the baking formula.

Increments of Bromate

The observation, that the higher the protein content of a flour the larger the dosage of Beta Chlora required to exhibit its maximum capability, naturally leads to a consideration of the effect of successive increments of bromate in relation to protein content and to the estimation of strength.

TABLE XIV

THE EFFECT OF AGING AND BLEACHING WITH BETA CHLORA ON FLOUR STRENGTH AS REVEALED BY THE BASIC AND BROMATE FORMULAS (0.001% $KBrO_3$) [1]

Flour number	Wheat grade	Per cent protein in flour [2]	Beta Chlora per barrel	Loaf volume 24 hrs. after bleaching			Loaf volume 30 days after bleaching			Response to aging		
				Basic formula	Bromate formula	Bromate response	Basic formula	Bromate formula	Blend formula	Bromate response	Basic formula	Bromate formula
		P.ct.	oz.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.
1	3 Northern	8.0	A 0.0	246	258	12	235	232	242	−3	−11	−26
			B 0.5	261	256	−5	247	235	252	−12	−14	−21
			C 1.0	238	234	−4	232	230	237	−2	−6	−4
			D 1.5	241	232	−9	235	230	235	−5	−6	−2
			H 2.5	225	—	—	—	—	—	—	—	—
3	3 Northern	11.0	A 0.0	263	324	61	267	317	310	50	4	−7
			B 0.5	277	333	56	282	342	307	60	5	9
			C 1.0	278	338	60	275	332	302	57	−3	−6
			D 1.5	283	335	52	282	325	302	43	−1	−10
			H 2.5	290	—	—	—	—	—	—	—	—
5	1 Hard	12.9	A 0.0	285	388	103	308	405	330	97	23	17
			B 0.5	320	377	57	342	390	327	48	22	13
			C 1.0	348	358	10	362	387	337	25	14	29
			D 1.5	357	379	22	367	395	317	28	10	16
			H 2.5	365	—	—	—	—	—	—	—	—
7	3 Northern	16.0	A 0.0	278	360	82	292	365	355	73	4	5
			B 0.5	288	375	87	317	380	372	63	29	5
			C 1.0	300	390	90	322	395	362	73	22	5
			D 1.5	310	391	81	340	405	357	65	30	14
			H 2.5	335	—	—	—	—	—	—	—	—

[1] Bakings were conducted with 50 gms. of flour. In the blend formula 40% of Pacific Club wheat flour was mixed with 60% of the flour under test and baked by the bromate formula. "H" samples were bleached approximately 8 weeks later than sub-samples A, B, C, and D.

[2] 13.5% moisture basis.

Harris (1932) baked samples of the 1930 Saskatchewan crop with varying dosages of potassium bromate and some of his data are shown graphically in Figure 2. This material included commercial, experi-

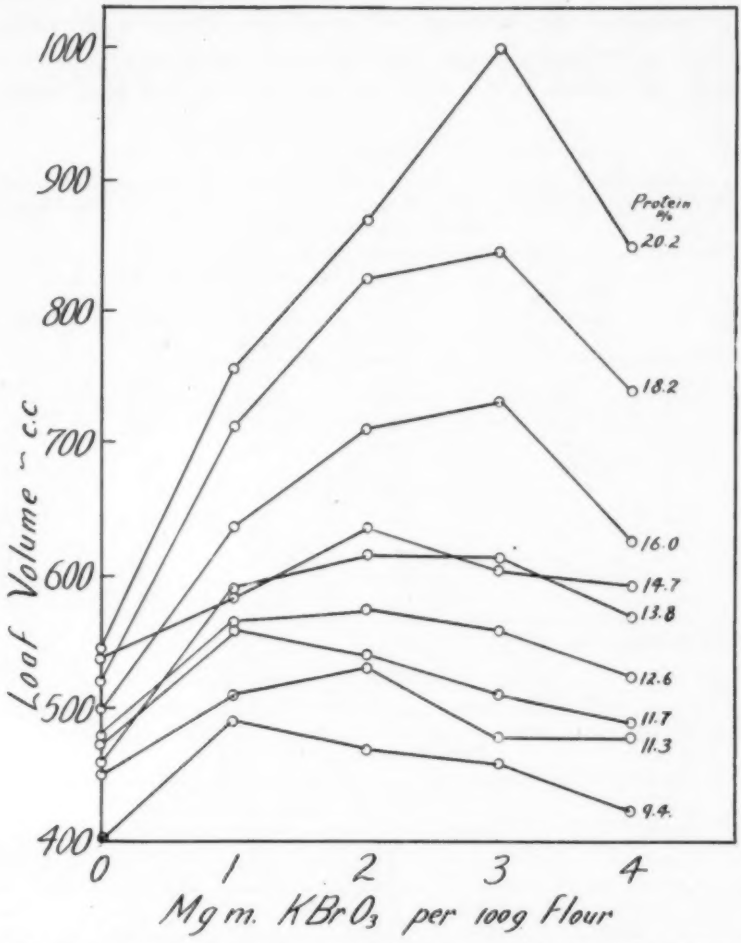

Fig. 2. The relation between protein content and loaf volume as revealed by successive increments of bromate. Graph constructed from data published by Harris (1932).

mentally milled, and mill stream flours, but the general effect of successive increments of bromate can be observed qualitatively. It will be noted that the spread in volume of these flours is very low with the basic formula and increases to a maximum with 3 mgm. $KBrO_3$, the ranges being 145 cc. and 630 cc. respectively. From the viewpoint of strength differentiation the formula involving 3 mgm. of $KBrO_3$ would be the most useful. The degree of stimulation obtainable is directly related to the protein content. The maximum strength of the

lower protein flour was revealed by 1 mgm. of $KBrO_3$, with flours of medium protein content 2 mgm. were required, while with the higher protein flours 3 mgm. produced increased volumes.

A series of straight grade flours experimentally milled from sound Marquis wheat of the 1929 and 1931 crops were baked with successive increments of bromate, in the Saskatchewan laboratory. The results are given in Tables XV and XVI and represented graphically in

TABLE XV

FLOURS OF THE 1929 CROP OF WESTERN CANADA BAKED BY THE BASIC PROCEDURE USING 50 GMS. OF FLOUR WITH THE ADDITION OF VARYING AMOUNTS OF POTASSIUM BROMATE

Sample number	Protein of flour [1]	Loaf volume (50 gm. formula)			
		Basic	0.001% $KBrO_3$	0.002% $KBrO_3$	0.004% $KBrO_3$
	P.ct.	cc.	cc.	cc.	cc.
1	8.0	230	235	220	155
2	9.8	230	290	280	250
3	11.1	260	300	270	230
4	12.6	250	308	365	275
5	12.6	320	320	305	235
6	13.6	220	360	360	280
7	16.1	185	350	425	395
8	17.6	185	355	420	535
9	17.7	190	330	465	470
10	18.3	210	320	435	380

[1] 13.5% moisture basis.

TABLE XVI

FLOURS OF THE 1931 CROP OF WESTERN CANADA BAKED BY THE BASIC PROCEDURE USING 50 GMS. OF FLOUR WITH THE ADDITION OF VARYING AMOUNTS OF POTASSIUM BROMATE

Sample number	Protein of flour [1]	Loaf volume (50 gm. formula)				
		Basic	0.001% $KBrO_3$	0.002% $KBrO_3$	0.003% $KBrO_3$	0.004% $KBrO_3$
	P.ct.	cc.	cc.	cc.	cc.	cc.
1	10.8	310	322	303	278	257
2	11.6	300	342	338	270	240
3	11.8	357	357	322	303	257
4	12.0	270	320	337	303	270
5	13.2	268	295	330	338	312
6	14.1	315	425	357	287	240
7	14.4	365	380	365	352	307
8	15.8	276	338	380	395	365
9	16.1	287	372	420	412	385
10	16.8	305	367	450	445	410

[1] 13.5% moisture basis.

Figures 3 and 4. There are some anomalies in these data, but the fact most clearly brought forth is that flours of low protein may show higher

volume by the basic formula than those of high protein content and that the former are more sensitive to the action of bromate than the latter. For example, referring to Table XVI and Figure 4, it will be noted that sample No. 3, with 11.8% of protein, occupied the second highest position by the basic formula, while sample No. 8, with 15.8% of

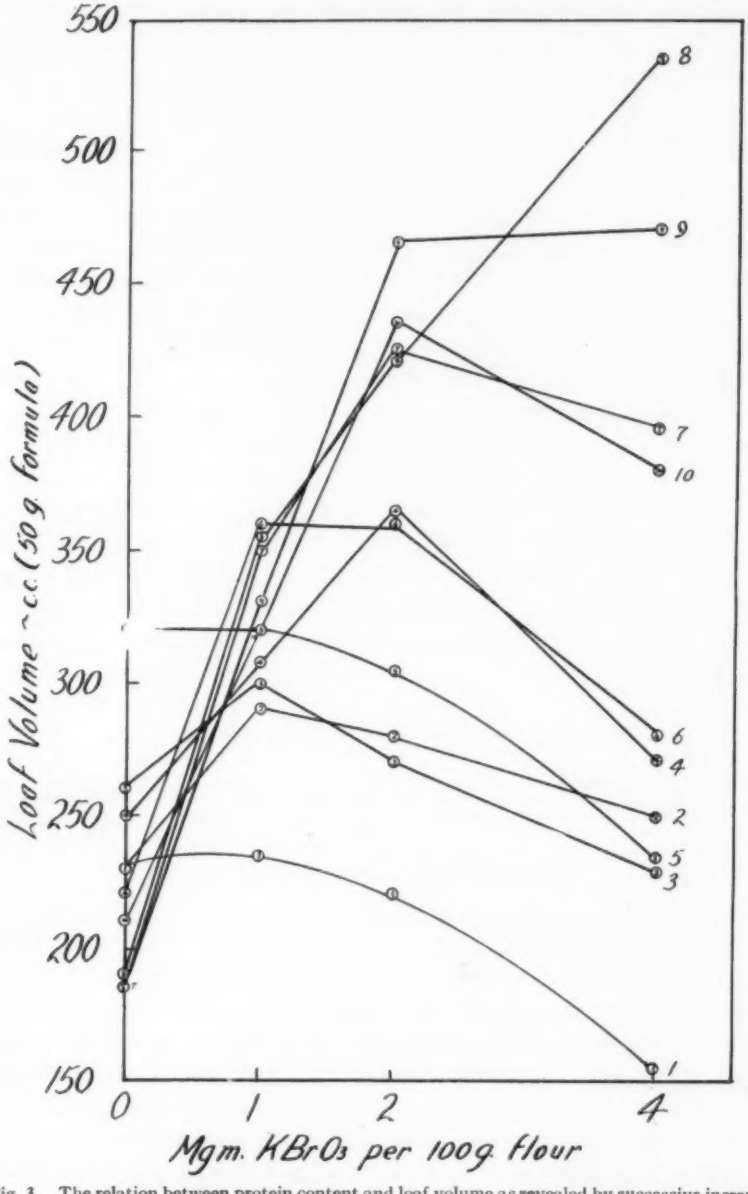

Fig. 3. The relation between protein content and loaf volume as revealed by successive increments of bromate. Straight grade flours experimentally milled from 1929 crop Western Canadian wheat. Samples are numbered in order of increasing protein content.

protein, was third from the lowest. There was not only a considerable increase in the range, but also a reversal of position with 0.001% $KBrO_3$, and still more with the 0.002% dosage, the latter giving relative placings more in line with the protein content than any of the other formulas.

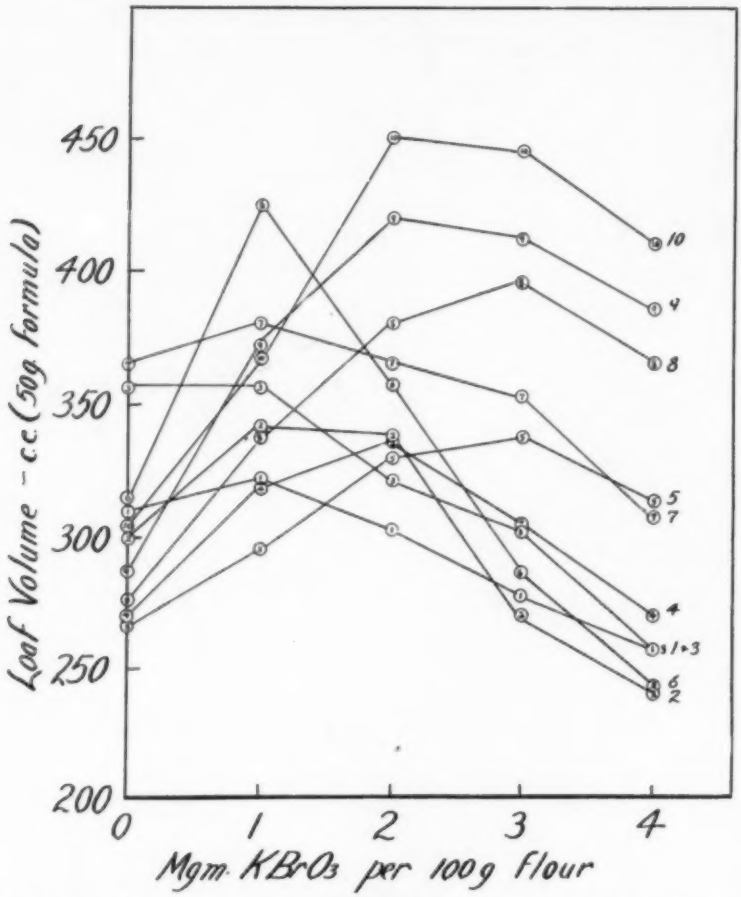

Fig. 4. The relation between protein content and loaf volume as revealed by successive increments of bromate. Straight grade flours experimentally milled from 1931 crop Western Canadian wheat. Samples are numbered in order of increasing protein content.

These points are also brought out in the 1929 data as may be observed from Table XV and Figure 3 and there seems to be little doubt that the basic is the least useful of these formulas. A comparison on that basis would yield very erroneous results because the five weakest flours, Nos. 1 to 5 inclusive, gave the highest loaf volume and even when the other loaf characters were considered, would still be judged the best in quality. A formula which places an 8.0% protein

flour above one with 18.0% protein cannot be regarded as giving a true measure of strength in the instance of Canadian wheats.

Attention should be directed to flour samples Nos. 2 and 6 in Figure 4. The former responded to the first milligram of bromate by 42 cc., but with a 2 mgm. dosage decreased in volume only 4 cc. On this basis the flour would be judged quite stable to oxidizers. However, when the dosage was raised to 3 mgm. a marked drop of 58 cc. occurred, which would indicate a decided sensitivity to overdosage. This is more strikingly shown by flour sample No. 6. It would seem, therefore, that the response alone is not sufficient to enable one accurately to describe a flour, but that it is necessary to carry the test to the point where the flour actually breaks down.

Summing up the results of these two experiments, it is evident that with Western Canadian samples the 0.001% bromate formula gives results more in line with commercial valuation than the basic formula, but even these may be misleading in many instances. It would seem advisable to use increasing amounts of bromate until the sample had definitely broken down in volume and from these results estimate the nature of the flour. This would, of course, include a "tolerance factor" about which little is known at present. There is a maximum volume obtainable by the use of bromate but before this could be considered a measure of general quality it will be necessary to ascertain how this is related to fermentation tolerance, to behaviour in blends, and to response to mechanical modification. It seems unlikely that we shall ever find a single baking formula that can be relied upon to give an accurate estimate of flour value.

Fermentation Tolerance Studies

In dealing with the question of fermentation tolerance in relation to the bromate baking test, two distinct considerations naturally arise: (1) The effect of the addition of bromate on the fermentation tolerance of bread doughs, and (2) the value of the differential baking test as an index of the fermentation tolerance of a flour.

In regard to the first question, A. W. Alcock, Chief Chemist of the Western Canada Flour Mills, Winnipeg, recently conducted a series of baking tests which are of interest. The experimental material consisted of three untreated mill streams: (1) Fifth middlings flour of 11.8% of protein and 0.38% of ash; (2) fifth break flour of 21.0% of protein and 1.10% of ash; and (3) "third low grade centrifugal" flour (a low grade middlings stream contaminated with germ) containing 12.4% of protein and 0.80% of ash. These flours were first baked with and then without bromate (0.001%) using fermentation times of 2.0,

3.25, 4.5, and 5.75 hours. The results led to a more extended series of baking tests, using fermentation times of 2, 4, 6, 8, and 10 hours, and different baking formulas. In the latter tests diastatic malt (Fleischmann's) was used at both a 1% and 5% level. With each of these percentages of malt, 0, 0.001% and 0.002% $KBrO_3$ was used. The loaf volumes obtained are plotted against fermentation time in Figures 5 and 6.

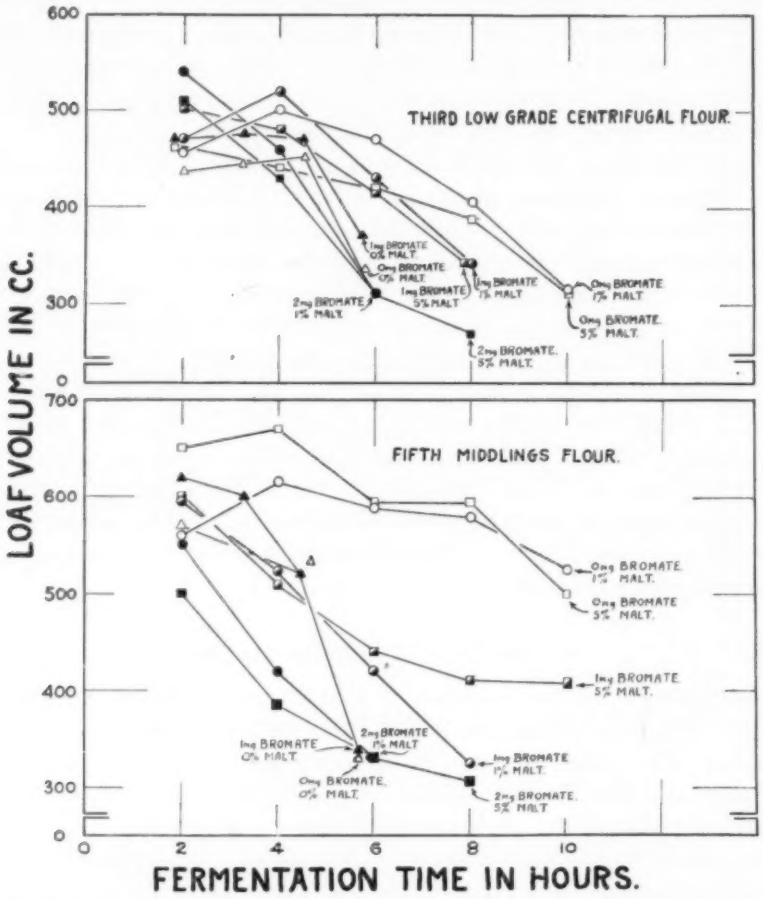

Fig. 5. Influence of additions of diastatic malt and successive increments of bromate on the fermentation tolerance of doughs made from fifth middlings flour, a high grade mill stream, and third low grade centrifugal flour, a low grade stream contaminated with germ.

Referring to Figure 5 and considering the fifth middlings flour, it will be noted that without malt the bromated and non-bromated doughs both failed together at 4.5 hours, which, on the basis of crust color, was undoubtedly due to inadequate gas production. The other flours yielded similar results and it was for this reason that the bakings

were repeated using successive increments of bromate in conjunction with diastatic malt. The added diastase greatly increased the fermentation tolerance of the dough, thus confirming the observations of Blish and Sandstedt (1927) that the maintenance of gas production is a

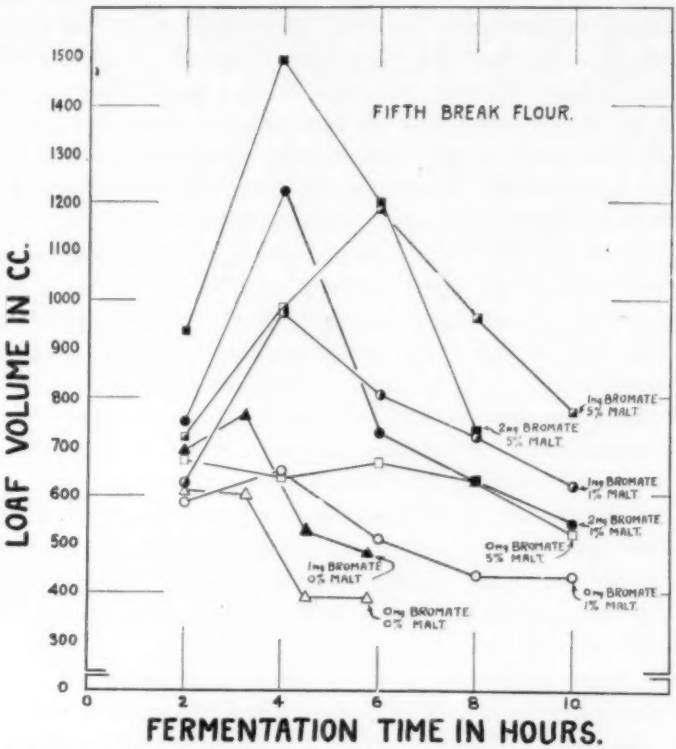

Fig. 6. Influence of additions of diastatic malt and successive increments of bromate on the fermentation tolerance of doughs made from fifth break flour, a high grade mill stream, and third low grade centrifugal flour, a low grade stream contaminated with germ.

more important factor in fermentation tolerance than the nature of the gluten.

These data clearly indicate, however, that gassing power is not the only factor involved. For both levels of diastase, the addition of each increment of bromate resulted in a decrease in fermentation tolerance. At corresponding fermentation times the crust colors were similar. It will be shown in the next section that potassium bromate has no measurable influence on gas production and hence the more rapid failure of the bromated doughs cannot be ascribed to this factor, but rather to a modification of the physico-chemical properties of the gluten.

As the fermentation time was extended, the doughs gradually

became "tough" and "solid" and the gluten was "shorter." These changes occurred earlier when bromate was added with the result that in certain instances it was impossible to mould the doughs at the 8 and 10 hour periods where 0.002% bromate was added. It is evident that the changes which are responsible for the development of the gluten during fermentation are greatly accelerated by the addition of potassium bromate with a consequent reduction in fermentation tolerance. Admitting that the rate of gas production in the final stages is an important factor in fermentation tolerance, these data show that the question of gluten quality or gluten condition cannot be entirely overlooked. Normally, the gassing power of bread doughs is the limiting factor and hence differences in flours due to the gas retention factor are hidden. The gas production factor depends more on the baking formula than on factors inherent in the flour itself. On the other hand, gas retention is more closely related to the character of the flour and for this reason some workers have suggested that the fermentation tolerance of a flour be considered as the leeway period under baking conditions which provide adequate gas production. This limitation of the term fermentation tolerance as applied to flours, although commendable from the scientific standpoint, would hardly receive much consideration from the practical baker. A flour would be regarded as inferior in tolerance if it failed to give equal results with another under particular baking conditions regardless of whether the failure was due to lower diastatic activity or to differences in gluten characteristics.

If the term fermentation tolerance of a flour is not limited to exclude the influence of varying diastatic activity, it is obvious that bromate response, as determined by the differential test, could not be a reliable index of the relative placing of flours in this regard. However, if a series of flours of similar protein content (an important factor influencing bromate response) were baked under conditions which provide adequate gas production, the data of Alcock suggest that bromate response would give a relative measure of their tolerance in so far as this is influenced by gluten characteristics.

Influence of Potassium Bromate on Gas Production and Gas Retention

All the evidence available at present points to the conclusion that the action of $KBrO_3$ is specifically related to a modification of the gas retaining capacity of bread doughs. It seems to have little or no effect upon the rate at which CO_2 is produced in the dough and, therefore, it may be assumed that it does not affect either the diastatic enzymes or the yeast. Some data obtained by Brockington (1932) serve to confirm these conclusions. Values for total CO_2 produced in

TABLE XVII

INFLUENCE OF POTASSIUM BROMATE ON THE CO_2 PRODUCTION AND RETENTION OF DOUGHS REPRESENTING 25 GMS. OF VARIOUS FLOURS

Flour number	Description of flour	Protein in flour [1]	CO_2 produced in 4 hours		Increase due to bromate	Maximum volume [2]		Increase due to bromate
			Basic formula	Bromate formula		Basic formula	Bromate formula	
		P.ct.	cc.	cc.	cc.	cc.	cc.	cc.
1	Experimentally milled	17.7	331	339	8	133	149	16
2	Experimentally milled	14.7	368	363	−5	100	130	30
3	Experimentally milled	9.7	392	396	4	124	144	20
4	Commercial patent	12.4	309	305	−4	129	158	29
4a	Commercial patent, no sugar	12.4	258	263	5	111	137	26
5	English wheat flour	6.7	327	322	−5	83	93	10

[1] 13.5% moisture basis.
[2] The maximum volume was determined with doughs that had received the first punch.

4 hours and the maximum volume attained by the doughs, determined by use of a modification of Bailey and Johnson's method (1924), are given in Table XVII. Four experimentally milled and one commercial flour were used, and as these flours represented a considerable range of strength, the data may be considered fairly representative. The commercial flour was tested by the normal formula and also without the addition of sugar. The average difference between the CO_2 produced in the basic and bromate doughs was only 0.5 cc. in the course of 4 hours fermentation. Saunderson (1930), working in the University of Manitoba laboratories, made similar comparisons, using buffered suspensions containing yeast, sucrose, salt and wheat germ. The suspension containing no bromate yielded 836 cc. of gas after 5 hours fermentation at 30° C., while the bromated suspension gave 837 cc.

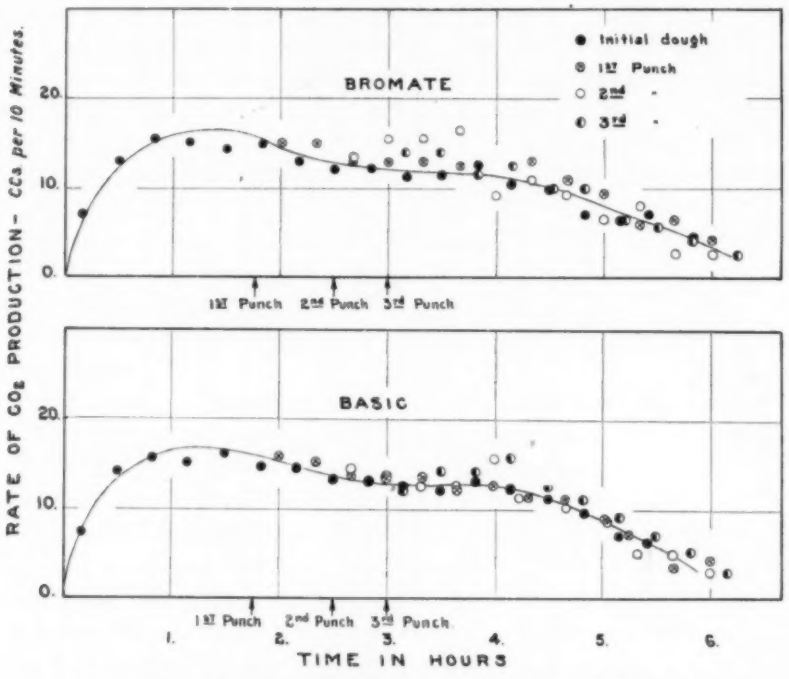

Fig. 7. Comparative rates of carbon dioxide production in doughs made by the basic and bromate formulas using a, first patent commercially milled, hard red spring wheat flour containing 12.5% protein (13.5% moisture basis). Rates are recorded for doughs started immediately after mixing, after the first punch (105 minutes), after second punch (155 minutes) and at time of moulding (180 minutes).

Referring to Table XVII, the volumes attained by the doughs in all cases were greater by the bromate than by the basic formula. It is evident, therefore, that the ability to retain CO_2 was increased as a result of the presence of $KBrO_3$ in the dough.

Not only is the total amount of CO_2 produced the same in both

basic and bromated doughs but the rate of CO_2 production throughout the fermentation period is also practically the same. This is shown in Figures 7 and 8 in which the rate expressed as cc. of gas produced per 10 minutes is plotted against time. These determinations were made on doughs straight from the mixer, doughs that had fermented 105 minutes (to time of 1st punch), doughs that had fermented 155 minutes (to time of 2nd punch) and on those that had fermented 180 minutes (to panning time). The curves for the "initial" doughs are drawn in, and the points for the others are shown around these curves. Figure 7 represents a standard commercial flour containing 12.5% protein, milled from Canadian hard red spring wheat; and Figure 8 represents a

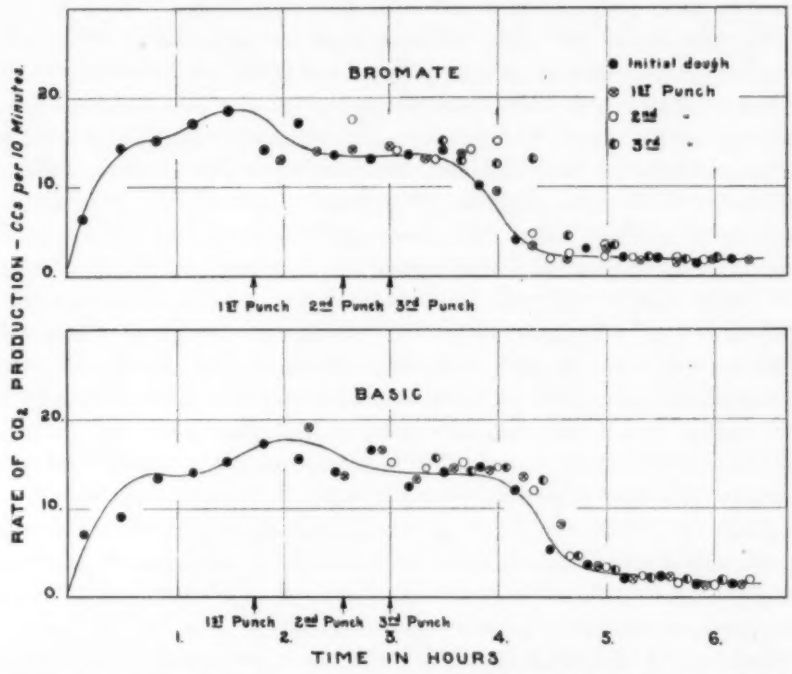

Fig. 8. Comparative rates of carbon dioxide production in doughs made by the basic and bromate formulas using a straight grade experimentally milled, hard red spring wheat flour containing 17.7% protein (13.5% moisture basis). Rates are recorded for doughs started immediately after mixing, after the first punch (105 minutes), after second punch (155 minutes) and at time of moulding (180 minutes)

straight grade flour containing 17.7% protein, experimentally milled from a 19.3% protein Marquis sample. The reason for the roughness of the rate curve of the latter flour is not known; it is not due to the fact that the flour was experimentally milled because the same type of curve has been observed with commercial flours.

These curves show quite clearly that at no time during the course of fermentation did the bromate dough differ materially from the basic

dough in rate of CO_2 production. It seems reasonable, therefore, to conclude that the presence of $KBrO_3$ in a dough affects neither the rate nor amount of CO_2 production.

The Fundamental Nature of Bromate Action

The observation that potassium bromate results in a modification of the gas retaining capacity of bread doughs leads to the conclusion that it exerts this effect through some action, either direct or indirect, on the gluten proteins. While not precluding the possibility of a direct affect, there is a great deal of circumstantial evidence to indicate that it acts primarily on the phosphatides, substances which have been shown to have a detrimental effect on gluten quality.

The presence of lecithin in wheat gluten was reported in 1893 and its influence on gluten was noted by Working (1924), who observed that prolonged washing of soft gluten from low grade flour removed phosphatide and increased its tenacity. On the other hand, the addition of phosphatides to flour injured the quality of the gluten. Sullivan and Near (1927) upon analyzing the glutens from patent, straight, and clear flours milled from the same wheat, found the lowest lipoid content in the patent and the highest in the clear. They pointed out that this was in inverse order to gluten quality. Subsequently these authors (1927a) reported the analysis of a series of wheats differing widely in origin and strength. While the lipoid content of the wheats examined varied within rather narrow limits (2.53% to 3.84%), they made the interesting observation that the ratio of lipoid to protein content gave a valuable index of gluten quality and flour strength—the higher ratios being given by the softer wheats.

Working (1928, 1928a) suggested that during fermentation the phosphatides are rendered more water soluble, resulting in development of the gluten and that the beneficial effects of small amounts of oxidizing agents might also be due to a similar action.

Geddes (1930) found that the addition of wheat germ to a highly refined mill stream resulted in a marked degradation in handling quality of the dough and a decreased loaf volume as determined by the basic method. The addition of bromate or the heating of the germ reduced its detrimental influence, and at the same time, reduced the fermentation period necessary to produce a loaf possessing the characteristics of normal fermentation. The more severe the heat treatment of the germ, the lower the response of the germ-flour mixtures to bromate. The experiments indicated that response to bromate and improvement of natural flour by heat treatment are associated with the presence of germ in the flour. It was also suggested that fermenta-

tion tolerance, the action of bleaching agents and the changes incidental to natural aging might be found to center around changes in certain germ constituents, presumably the phosphatides.

While the validity of these premises has not yet been definitely established, considerable confirmatory evidence has been obtained, Saunderson (1930) extended the work of Geddes (1930) by a more extensive range of heat treatments on a sample of wheat germ conditioned to different moisture levels, and by a detailed study of the treated material as it affected the baking quality of a highly refined flour. Biochemical studies were also conducted on these samples and some of the data are compiled in Table XVIII.

It will be noted that the control samples, as well as those subjected to heat treatment, differed in their effect on the baking behaviour of fifth middlings flour according to their moisture content. The higher the moisture content of the germ the less its deleterious effect and the greater the change induced by a particular heat treatment. The chief chemical changes were a decrease in the lipoid phosphorus, and in the peptizability of the germ proteins as a result of heat denaturation. There is a close parallelism between these changes and the effect of the germ on the baking behaviour. The coagulation of the germ proteins does not appear to explain these results, but they seem rather to be linked up with the destruction of phosphatides. As the lipoid phosphorus decreases, the basic loaf volume increases and the response to bromate decreases. These changes were accompanied by a marked change in the handling qualities of the dough. Unheated germ of low moisture content produced a marked softening action on the gluten, particularly in the earlier stages of fermentation in doughs made without bromate. The addition of bromate greatly improved the handling quality. However, in the bromated doughs containing high moisture germ, given the most severe heat treatment, the dough became "harsh" and lacked resiliency. This was particularly evident with extension of the fermentation time in fermentation tolerance studies. Thus, heat treatment of germ, the addition of bromate, or the extension of fermentation time produced the same trend in regard to baking behaviour and when combined resulted in an over effect.

Partial ether extraction of the germ brought about a considerable reduction, and acetone extraction a lesser reduction, in its harmful effects on gluten quality. The acetone was found to extract less phosphatide than ether. It should be pointed out that values for lipoid phosphorus given in Table XVIII are reported in per cent of the germ. As the alcohol-ether extract constituted approximately 12.4% of the sample, the decrease in the phosphorus content of the extracted lipoids was very marked.

TABLE XVIII

BIOCHEMICAL CHANGES INDUCED IN WHEAT GERM BY HEAT TREATMENT AT DIFFERENT MOISTURE LEVELS, AND THEIR EFFECT ON THE BAKING BEHAVIOUR OF GERM-FLOUR MIXTURES (COMPILED FROM UNPUBLISHED DATA OF SAUNDERSON (1930))

Heat treatment		Loaf volume of germ-flour mixtures [1]			Analysis of germ			
Temperature	Time	Basic formula [2]	Bromate formula	Bromate response	Lipoid phosphorus (dry matter basis) [3]	Titratable acidity as lactic [4,5]	pH [6]	Protein peptized by N/2KI [5,7]
° F.	hrs.	cc.	cc.	cc.	P.ct.	P.ct.		P.ct.
				Moisture of Germ = 7.5%				
Control		571	669	+98	.089	.76	6.47	19.5
170	2	578	662	+84	.086	.66	6.42	18.5
170	6	612	661	+49	.086	.67	6.39	17.6
170	10	614	670	+56	.082	.68	6.34	17.0
				Moisture of Germ = 13.3%				
Control		611	660	+49	.068	.76	6.32	18.8
170	2	635	716	+81	.053	.61	6.23	12.8
170	6	685	702	+17	.051	.61	6.16	11.9
170	10	688	670	−18	.046	.63	6.12	10.5
				Moisture of Germ = 17.1%				
Control		672	702	+30	.047	.82	6.43	18.0
170	2	672	685	+13	.044	.61	6.10	11.6
170	6	682	637	−45	.046	.59	6.25	10.6
170	10	678	625	−53	.042	.67	6.04	9.5

[1] Flour without germ gave a basic volume of 629 cc. and a bromate volume of 696 cc.
[2] In the baking tests 10% of germ calculated to 13.5% moisture basis, was mixed with 90% fifth middlings flour.
[3] Lipoid phosphorus was determined by a modification of Fiske and Subbarow's (1925) method on the total lipoids extracted by the method of Sullivan and Near (1927).
[4] Titratable acidity determined on water extracts by the official A. A. C. C. procedure.
[5] 13.5% moisture basis.
[6] pH determined by the quinhydrone gold electrode on water extracts prepared by the A. A. C. C. method.
[7] Peptized protein determined by the method described by Geddes and Goulden (1930).

The evidence, though indirect, points to a close relation between phosphatide content and the baking behaviour of flour-germ mixtures. Further unreported experiments have shown that the phosphatide content of bread doughs decreases as the fermentation proceeds, but that the addition of bromate brings about a greater and more rapid decrease.

There is some indication in these experiments that there is an optimum concentration of phosphatide in relation to the most desirable physical properties of gluten, excessive phosphatide resulting in "soft" gluten, and a deficiency causing a harsh, tough, and non elastic gluten. In this connection it is interesting to recall that Sullivan and Near (1927a) found that the ratio of lipoid to protein gave a valuable index of gluten quality and that the higher ratios were given by the softer wheats.

The germ samples in Saunderson's (1930) studies were stored at a temperature of approximately 3° C. and the difference in lipoid phosphorus content at the different moisture levels suggested that aging might also bring about a reduction in phosphatide. Winkler (1931) aged wheat germ at two moisture levels and conducted studies similar to those of Saunderson. A portion of these data is summarized in Table XIX.

In regard to the baking results it should be mentioned that the bakings after the 19th day of aging were carried out by a different operator, and this, together with the intervals of time elapsing between the baking tests for the different periods, must be considered in evaluating these data. Comparisons between the moist and dry germ at corresponding intervals are quite legitimate since the baking tests were conducted on the same day.

It will be noted, however, that there is a general trend towards a reduction in the deleterious effect of the germ on loaf volume particularly by the basic method and a decrease in bromate response as aging progresses. The improvement in the handling quality of the doughs was very noticeable.

The most interesting feature of these results is the remarkable accelerating influence of moisture in promoting the changes incidental to aging. In this series the peptizability of the germ proteins remained unchanged, but there were marked decreases in lipoid phosphorus, in pH, and increases in acidity, particularly at the higher moisture level.

Saunderson (1930) determined titratable acidity on water extracts and found it very difficult to judge the end points, while Winkler (1931) used the Greek acidity method and found it somewhat more satisfactory in this regard. While heat treatment reduced titratable acidity, as compared with the control, presumably as a result of decreased

TABLE XIX

BIOCHEMICAL CHANGES OCCURRING IN WHEAT GERM UPON NATURAL AGING AT TWO MOISTURE LEVELS, AND THEIR EFFECT ON THE BAKING BEHAVIOUR OF GERM-FLOUR MIXTURES

Time of aging	Loaf volume of germ-flour mixtures [1]			Analysis of germ			
	Basic formula	Bromate formula	Bromate response	Lipoid phosphorus (dry matter basis) [2]	Acidity as H_2SO_4 (dry matter basis)	pH	Protein peptized by N/2KI [3]
days	cc.	cc.	cc.	P.ct.	P.ct.		P.ct.
			Moisture of Germ = 7.0%				
7	530	655	125	.100	.127	6.76	20.5
19	575	600	25	.104	.158	6.77	20.5
33	560	630	70	.094	.160	6.77	20.5
73	575	620	45	.090	.172	6.75	20.5
123	610	640	30	.089	.209	6.75	20.5
165	595	630	35	.048	.266	6.68	—
			Moisture of Germ = 13.0% Approximately				
7	525	585	60	.102	.133	6.77	20.5
19	600	640	40	.093	.207	6.70	20.5
33	565	625	60	.078	.233	6.72	20.5
73	610	660	50	.029	.325	6.52	20.5
123	660	670	10	.024	.547	6.45	20.5
165	630	650	20	.014	.993	6.03	—

[1] In the baking tests 5% germ was mixed with 90% of fifth middlings flour.
[2] With the exception of acidity, the analytical determinations were carried out as outlined in the footnotes to Table XVIII. Acidity was determined by the Greek method since it was found to give a more satisfactory end point than the A. O. A. C. method.
[3] 13.5% moisture basis.

peptizability of the germ proteins, it is interesting to note that the range in acidity of the heat treated samples is not great, despite wide differences in their effect on the baking behaviour of flour. A limited number of experiments showed that acidification of doughs made with unheated germ did not simulate the effects of heat treatment or aging. Of the chemical changes investigated, the destruction of phosphatide seems to offer the most logical explanation for the similarity in the effect of heat treatment and natural aging in reducing the injurious effect of germ on gluten quality.

The question naturally arises as to whether the destruction of phosphatide is due to oxidation or hydrolysis. The accelerating influence of potassium bromate in destroying phosphatide and the parallelism between its effect on gluten development and that brought about by natural aging, heat treatment, and the use of bleaching agents, such as nitrogen trichloride, indicate that oxidation is the fundamental reaction involved. This has been previously suggested by Working (1928a). On the other hand, the increased rate of destruction at the higher moisture levels suggests that the decrease is due to hydrolysis of phosphatides by phosphatidase such as lecithinase.

A study of the extracted lipides throws some light on this question. Winkler (1931) determined the iodine numbers of the lipides extractable from the germ samples with anhydrous ether. The iodine numbers were found to increase with time of aging, this increase being approximately 4 and 7 units after 165 days of aging for the low and high moisture samples respectively. He pointed out, however, that it was difficult to secure consistent results on different extracts of the same sample, apparently due to oxidation during the removal of the residual ether after extraction. The only possible explanation of this apparent anomaly would be an increase in the fatty acid content of the lipides due to hydrolysis, the fatty acids liberated masking any concurrent oxidation by increasing the iodine number. This was proved experimentally by the marked increase in the acid values of the lipides extracted from aged germ. It was, therefore, necessary to prepare and study the insoluble fatty acids rather than the mixture of acids and glycerides constituting the extract.

Solomon and Binnington (1932), working in the University of Manitoba laboratory, have developed special apparatus and technique whereby the entire series of operations involved in the preparation of fatty acids could be carried out in an inert atmosphere. The entire technique of the Wij iodine value determination was also subjected to critical examination and certain modifications introduced which were found to increase the precision. These methods were employed in determining the iodine values of fatty acids obtained from three of

Winkler's germ samples—the original sample which had been held in storage at 3° C., and the samples aged for 165 days at 7.0% and 13.0% moisture at room temperature and subsequently stored at 3° C. until the analyses were made. The iodine numbers of the fatty acids were 130.3, 129.0 and 126.2, respectively. While these results show that some oxidation of the lipides of the germ had taken place on aging at room temperature, the oxidative changes were of small magnitude in comparison with the extent of hydrolysis. Oxidation and hydrolysis may both play a part in the destruction of phosphatide but the data at hand indicate that hydrolysis is the chief reaction involved.

Another line of evidence has been obtained which gives ground for the belief that oxidation is not the only or indeed the principal effect of chemical improvers in bread doughs. Saunderson (1930) conducted a series of comparative baking tests on flour germ mixtures using sodium bromate, potassium bromate, potassium chlorate, potassium iodate, calcium peroxide, and potassium persulphate. These improvers were added at rates which were calculated to yield the same quantities of oxygen in each instance. If their action was due entirely to oxidation the effects should be similar, or at least proportional to their ease of decomposition, but the results obtained were quite different for the various improvers. Subsequent studies have indicated a lyotropic series and this may be interpreted as a direct and specific ionic effect on the gluten proteins.

The indirect evidence obtained in these studies indicates that the phosphatides have an important bearing on the baking behaviour of flours. These substances may prove to be, in large part, a common basis for all forms of flour improvement and gluten development whether this is brought about by mechanical modification, by fermentation, by bleaching agents, or by the addition of oxidizing agents, such as potassium bromate, to the baking formula. The present studies can only be regarded as preliminary and extensive research will be necessary before their role in this connection is elucidated.

Discussion

The discussion in this paper has been based on the limited application of the basic and bromate formulas to hard red spring wheat flours. For the most part they were experimentally milled and baked after only a limited amount of natural aging and without any bleaching treatment. For the sake of simplicity, loaf volumes only have been dealt with, although it is realized that other characteristics, such as type and shape of loaf, grain and crumb texture are valuable criteria of the baking value of a flour. In general, however, in the instance of

strong flours, these characteristics are closely related to volume, and a consideration of the relative loaf volumes obtained by different baking procedures serves to illustrate the general adaptability of any particular baking method to the evaluation of this class of experimental material.

Western Canadian wheats are valued in Europe for their ability to confer strength on a blend with softer wheats. In laboratory testing it is essential to secure a measure of the inherent strength or maximum capabilities of each sample under investigation. The evidence presented is very convincing that the basic procedure fails to reveal the true relative strength of unaged and unbleached experimentally milled hard red spring wheat flours and that as a single measure of quality the bromate formula is distinctly superior. However, comparisons with the blend formula indicate that the bromate test, using 0.001% $KBrO_3$, fails to reveal differences in strength in the instance of the higher protein ranges, and in these cases it seems necessary to use larger increments of bromate. The question arises whether the maximum differences obtainable between flours by the use of successive increments of bromate is in any way related to their relative fermentation tolerance in so far as this characteristic is associated with gluten properties. This important question cannot be definitely answered at the present time.

In evaluating strength, it is important that variations in the diastatic activity of the flours under examination should not be a limiting factor, and extensive studies are necessary to determine the best means by which this may be accomplished. It seems altogether unlikely that a single standard baking procedure can ever be devised which will reveal the true relative strength of a series of flours varying widely in protein content and diastatic activity. The use of supplementary procedures, such as those outlined by the A. A. C. C. Baking Test Committee, is particularly essential in evaluating hard red spring wheat flours which are sold largely for blending purposes and baked by the great variety of procedures in use in European bake shops.

Summary

Results of baking tests conducted on flours experimentally milled from Western Canadian hard red spring wheats lead to the conclusion that the bromate formula gives a much better measure of the relative strength of such flours than the basic formula.

The bromate volumes are more highly correlated with protein content than the basic, and the regression of loaf volume on protein is linear over a greater range.

The bromate formula is more sensitive than the basic in indicating modifications in flour strength due to heat treatment or the presence

of green, frosted, or immature kernels in the wheat mix. The basic formula seems the more susceptible to variations in the enzymic activity of flours.

In estimating flour strength, the direction and magnitude of bromate response is of limited value unless considered in conjunction with the basic and bromate volumes.

Bromate response is conditioned, in part, by protein content and, in part, by factors associated with gluten quality.

Natural aging of flour resulted in a decrease in bromate response.

Volumes obtained by the bromate formula on untreated flours were indicative of the results to be expected from the same flours fully matured by artificial means and baked by the basic formula.

Baking tests involving the use of increasing quantities of potassium bromate showed that the tolerance of flours to bromate increased with protein content, although some irregularities were observed.

When gas production was not a limiting factor, the apparent fermentation tolerance of three mill stream flours progressively decreased upon the addition of increasing dosages of bromate to the baking formula.

Potassium bromate does not influence the rate nor the amount of carbon dioxide production in bread doughs, but modifies their gas retaining capacity indicating that it exerts a direct or indirect action on the gluten proteins.

Studies on wheat germ indicate that the action of potassium bromate on gluten quality is largely indirect. The deleterious effect of wheat germ on the loaf volume of flour-germ mixtures, as determined by the basic formula, is reduced by heat treatment or natural aging, particularly at high moisture content. Extension of the fermentation time or the addition of potassium bromate to the baking formula also reduced the injurious effects of wheat germ. These factors all resulted in a decrease in lipoid phosphorus, indicating that their parallel effect in modifying baking behaviour may be linked with the destruction of phosphatides.

Studies on the lipides extracted from wheat germ aged under different conditions, suggest that the destruction of phosphatide is due chiefly to enzymic hydrolysis.

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MEASURING AND RECORDING SOME CHARACTERISTICS OF TEST SPONGE CAKES

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(Read at the Convention, May, 1932)

While the scientific literature regarding bread is fairly extensive, much less of a scientific nature has been published concerning cake. Most of the literature that has appeared on cake is practical rather than scientific. Relatively little of a quantitative nature has appeared. An exception to this is the series of articles on various phases of cake baking by Glabau (1930–32) where quantitative measurements of specific gravity of batter and cake volume are given. Definite progress in putting cake baking tests on a more scientific basis has been made through the excellent work of the A. A. C. C. Committee on Methods of Testing Cake and Biscuit Flours, under the chairmanship of M. M. Brooke (1928–31).

The present work was undertaken to study the cake baking quality of eggs. We believe, however, that the problems involved and the methods employed are of general interest to any one making a scientific study of cake baking. Sponge cake was used in these tests, but most of the methods described would apply with little change to other types of cake.

As the object of these tests was to determine what results would be obtained in a commercial bakery, methods of a commercial type for making the cake were purposely used. This applies to the formula, size of pan, time of bake, etc.

Once the cakes were baked, the problem remained to record the results obtained and to measure quantitatively as many characteristics as possible. It is universally admitted that quantitative results should be the ideal of scientific research. While the methods for making the cake have been worked out with great exactness with regard to weights, temperatures, times, etc., few quantitative measurements have previously been made on the finished cakes with the exception of weight and volume. Except for these two determinations, the decision as to what has been accomplished by baking tests has heretofore rested entirely on personal opinion.

Test Baking Details

Apparatus: The mixer used was a small, three-speed Hobart mixer with 10-quart bowl and wire whip. The pans were 5″ × 7″ at the top, 1⅞″ deep, and 4½″ × 6½″ at the bottom. Paper liners were used in the pans. A Despatch electric oven, style No. 101, with thermostatic control, was used.

Method of Procedure: Put in bowl and heat 70° to 75° F.: 26.4 oz. whole egg, 26.4 oz. sugar, and 0.53 oz. salt; whip 7 minutes at high (third) speed.

Dissolve in a different container and bring to 140° F.: 1.21 oz. powdered skim milk, 5.30 oz. sugar, 6.00 oz. water; add to whipped egg at low speed (approx. 15 seconds).

Sift together three times: 22 oz. flour (soft winter wheat patent), and 0.25 oz. baking powder (Fleischmann's); stir in at second speed for 10 seconds, and at third speed for 10 seconds.

Scale at 6.5 oz.

Bake at 390° to 400° F. for 21 minutes.

Twelve cakes were normally baked in each lot. From three to four bakings, usually on different days, were made, giving a total of 36 to 48 cakes from each different sample of eggs tested.

The finished cakes were allowed to cool one hour on wire racks and then stored for 24 hours in tight containers, until tested.

Specific Gravity of the Batter

Glabau (1930), Alexander (1931), and others, have determined the specific gravity of cake batter by measuring the weight of a standard cupful. In this study, the same method was followed using a cylindrical cup of the following inside dimensions: 57 mm. high × 72 mm. diameter. Determinations were made of the specific gravity of the eggs and sugar after beating, and of the finished dough containing all ingredients ready for scaling. When the eggs were reasonably good, the differences in specific gravity noticed were small, and little correlation was found between the lightness of the batter or dough and the volume of the finished cake.

There is wide-spread opinion among bakers that there is a marked difference in the "beating time" of different lots of eggs; that is, that some eggs take much longer to beat up to maximum volume than others, other factors being constant. It is evident that by measurement of specific gravity at intervals, the beating time of the eggs may be determined. One laboratory experiment in which this was done is shown in Figure 1. Here it is seen that the egg-sugar batter beats up to maximum lightness in about 7 minutes, and that after that the lightness decreases.

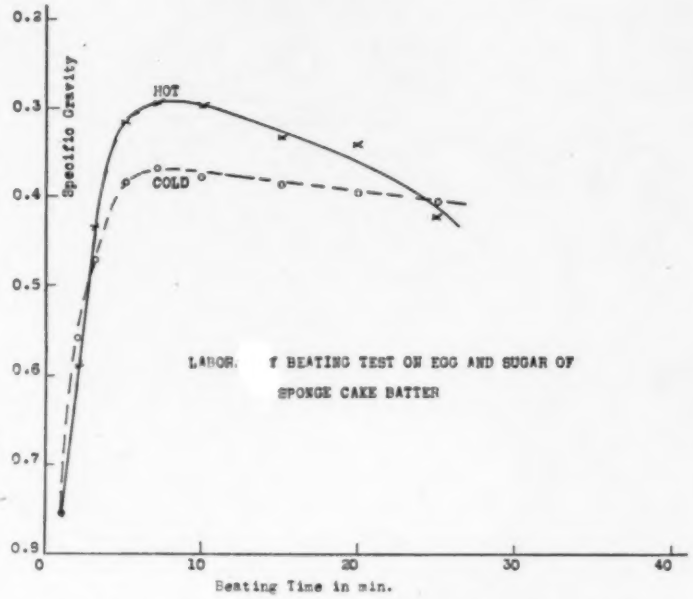

Fig. 1. Laboratory beating test on egg and sugar of sponge cake batter.

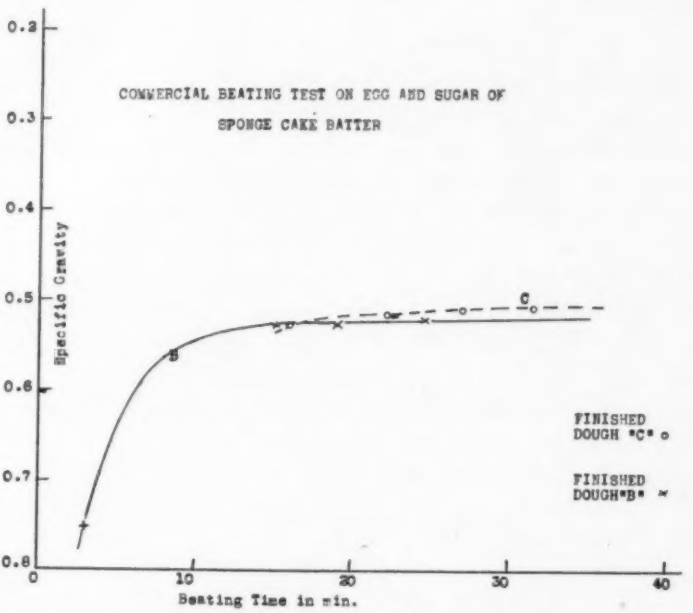

Fig. 2. Commercial beating test on egg and sugar of sponge cake batter.

An interesting comparison is seen in the same determination when the cake batter is mixed on a commercial scale. Here a mixer is used with two horizontal beaters and holding 250 lbs. of the total mix. In this mixer it took 10 minutes to beat up the eggs and sugar to maximum lightness, whereas in the laboratory mixer this required but 7 minutes. Likewise in the commercial mixer, there is no evidence of a loss of lightness on extending the beating time for more than 20 minutes beyond the maximum (Figure 2), whereas in the laboratory studies the lightness decreased in less than 1 minute after the maximum was passed. In general, the action of the laboratory mixer is both quicker and more severe than that of the commercial mixer and there is more danger from over-mixing. This is similar to the comparison between laboratory and commercial bread mixing, as has been pointed out by Platt (1931a).

In taking the specific gravity of the batter from a large commercial mixer, it was found to be very important to fill the test cup with batter immediately after the mixer is shut down. As soon as the mixer stops, bubbles rise and the specific gravity of the batter near the top of the mixer gets rapidly less. This may introduce a large error. A pallet knife was found most convenient for filling the test cup, leveling off the top and scraping the sides of the cup preparatory to weighing.

Measuring Cake Volume

Whereas seed displacement methods are reasonably satisfactory for bread and certain types of cake, these methods were not found satisfactory for sponge cake due to the compressibility of this product. The present cakes were comparatively symmetrical and flat on top which simplified the problem of volume determination. The following method was adopted, based on one developed by the Department of Household Arts, Teachers' College, Columbia University.

After baking, the cakes are allowed to cool at room temperature on wire racks for one hour. They are then cut crosswise at the center. The cut surface is placed against a piece of paper and the outline drawn with a soft pencil, being especially careful to avoid exerting any pressure against the cake with the pencil. This procedure gives an outline of the cross section of the cake at the center. The area of this cross section is measured with a planimeter. It was found that this area was proportional to the volume. Multiplying the area in square centimeters by a constant 15.07 would give the volume of the cake in cubic centimeters. Ordinarily this conversion was not made and the area of the cross section was used directly, expressed as the "Index of Volume." The volumes of 6 cakes out of each baking were measured in this way, and the average used for scoring.

An investigation was made to find out whether a more reliable determination of volume could be obtained by including in our calculations the area of the longitudinal section also. Evidently the area of a cross section equals the breadth (B) $\times$ thickness (T). The area of a longitudinal section equals the length (L) $\times$ thickness (T), therefore,

$$\frac{\text{Area of cross section} \times \text{area of longitudinal section}}{\text{Average thickness}} = \frac{B \times T \times L \times T}{T} = \text{Volume.}$$

It was found that having the outline of the longitudinal section, the average thickness could be determined quite accurately by means of a transparent ruler drawing a line near the top which included above it and below it an equal area of "hills" and of "hollows," respectively. Many determinations of volume were made using the area of cross section alone and the cross section combined with the longitudinal section. It was found that these methods checked well, but that no advantage was gained by including the longitudinal section in the calculations.

The adopted method was also checked against the seed displacement method by allowing the cakes to get hard and stale, so that they would not be compressed by the seed. The results were found to check well with the cross section method.

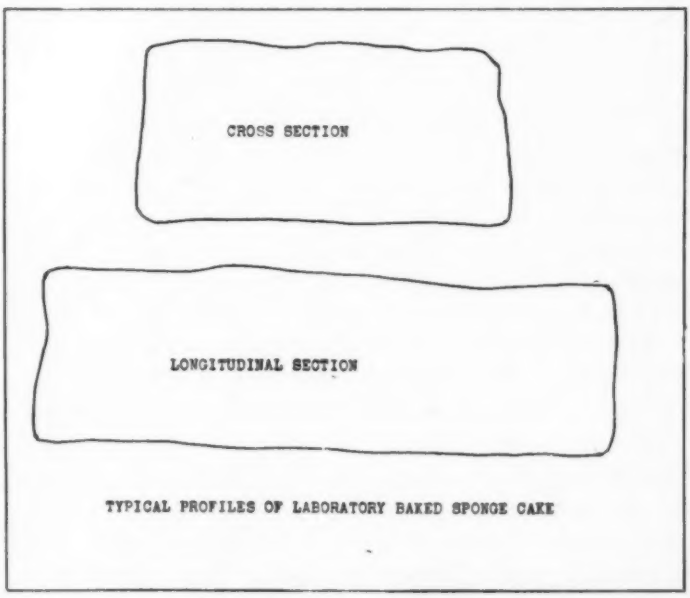

Fig. 3. Typical profiles of laboratory baked sponge cake.

The appearance of the cross section and longitudinal section of these cakes is shown in Figure 3.

This method has several incidental advantages. First, the outline of the cross section gives not only an idea of size, but also a valuable idea of the shape of the cake. It shows at a glance whether the top was concave or convex and whether there was any break of the crust in the center. Second, this method has many points of convenience. Once the outlines of the cross section are drawn, the measurements and calculations can be made at any time most convenient, sometimes by a different operator. This is of importance where experiments are being tried in a commercial bakery, where time, space, and facilities for accurate scientific measurements are usually limited. In this case, 10 or 20 cakes from each experimental batch can be set aside on a rack until cool. These are then weighed and the outlines of cross section drawn. These cross sections are then measured and averaged when most convenient. This may be done in the laboratory, often in a different city from the bakery.

This method would evidently afford an easy manner by which cakes made in different cities or at different times could be compared with one another, when it would be impracticable to bring the cakes all together for direct comparison.

Shape and Grain

With cakes having a delicate grain such as sponge cakes, only fair success was achieved by means of ink impressions (see Child and Purdy, 1926). These impressions were made by using stencil ink, which was transferred to the cut surface of the cake by means of a soft brush. This surface was then pressed upon a piece of paper.

Better results were obtained by means of photography. An example of results obtained is shown in Figure 4. The method used by us, using apparatus within the reach of any amateur, is as follows:

The camera used is a Voightlander "Avus" with the following specifications: "Skopar" anastigmatic lens, f:4.5, mounted in Compur shutter; plate holders equipped with cut film sheaths to take 3¼" × 4¼" cut film (Supersensitive Panchromatic); ground glass screen for exact focusing. The camera is mounted on a tripod.

The cakes to be photographed are placed on a small set of shelves, cut surface toward the camera. The light comes from two 200 watt bulbs, mounted in reflectors on movable stands. These are placed so as to give an angle of illumination of 20 degrees with the face of the cake. This angle of illumination, according to Harrel (1930), gives the best possible detail of the grain with the least apparent harshness.

With this illumination, the lights at a distance of 6 feet from the samples, and the camera at approximately 3 to 4 feet, depending on the number of samples and on the magnification desired, the exposure given is 1½–2 seconds at f:11.

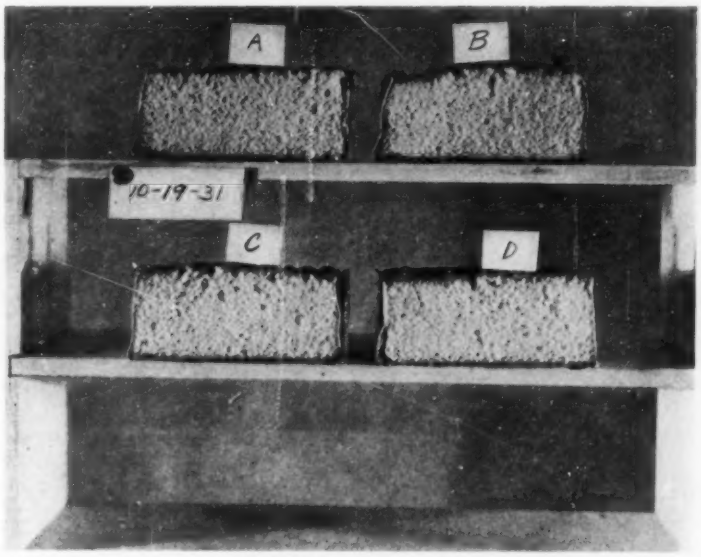

Fig. 4. Typical photographic record of grain and general appearance of sponge cake.

Panchromatic film and a filter to compensate for the light source should be used if true color values are desired in the photographs. Regular film will not reproduce the values with a sufficient degree of exactness. The crust of cake, bread, etc., will always appear burnt in comparison with the crumb unless the proper films and filter are used. The prints made from Panchromatic film, using the correct filter, should be compared with the original cakes in order to recognize and appreciate the faithfulness of the recorded color values.

Even illumination of the series of samples and uniform developing and printing technique are absolutely necessary to insure correct comparisons of color values.

Texture

Texture has been defined for bread by the American Institute of Baking as follows:

"Texture is determined by the sense of touch. It depends on the physical condition of the crumb and to a minor degree is influenced by the grain. It is an expression of the elasticity, softness or pliability, and smoothness or silkiness of the crumb.

"The cut loaf should be so elastic that when pressed by the finger it resumes its original shape. The ideal texture is soft and velvety without weakness or doughiness, and should not crumble."

This will apply also to cake, especially sponge cake.

Speaking more exactly in physical terms, texture is principally a combination of compressibility, elasticity, and tensile strength. Crumbliness would probably manifest itself in connection with low tensile strength. These three physical characteristics should all be measurable.

Measurement of Compressibility

Compressibility and elasticity under compression are conveniently measured by the apparatus described by Platt (1930) for making this measurement on bread. This consists essentially in applying a plunger under a given load to a block of the crumb of the cake and measuring the deformation in a given time. Degree of elasticity may be determined by the degree to which the plunger returns to its original position when the load is removed, and the degree to which it obeys Hooke's law under different loads.

The apparatus for making compressibility measurements on cake is shown in Figure 5.

As can be seen by examination of Figure 5, the apparatus consists of a remodeled balance. The additions consist of an adjustable platform (*a*) to support the test piece and a plunger (*b*) through which the weight is applied to the sample. This plunger has a circular face 1¼″ in diameter. This bears normally on the cut surface of the sample.

The right-hand pan (*c*) carries a known weight, balanced by a chain of identical weight on the left-hand pan (*d*). There is also a small weight of a few grams on the right-hand pan to hold the plunger lightly to the surface of the cake.

The indicator and scale (*e*) provide a means of measuring the penetration of the plunger. The scale reading magnifies the penetration 3.9 times.

The test pieces are cut to 2½″ × 2½″ × 1″, with particular care to obtain parallel top and bottom faces and to remove any sub-crust crumb that is not uniform with the rest of the cake.

The procedure in performing the test is as follows: Place the desired weight, usually 100 gms. for 24-hour old sponge cake, on the right-hand pan and the corresponding chain weight on the left-hand pan. Cut the sample block, observing the above precautions. Two of these blocks can be cut from each sponge cake. Any abnormalities, such as excessively large holes directly under the plunger, irregularities in the texture due to poor mixing, etc., should be avoided as far as possible.

The test piece is laid on the supporting plate, the plunger allowed to come to rest on the surface of the cake, and the pointer adjusted to zero by means of the adjusting screw (*f*). The chain is then lifted smoothly from the left-hand pan, and the weight allowed to act for 1 minute. Time is most conveniently taken with a stop-watch, starting timing as the chain begins to rise from the pan.

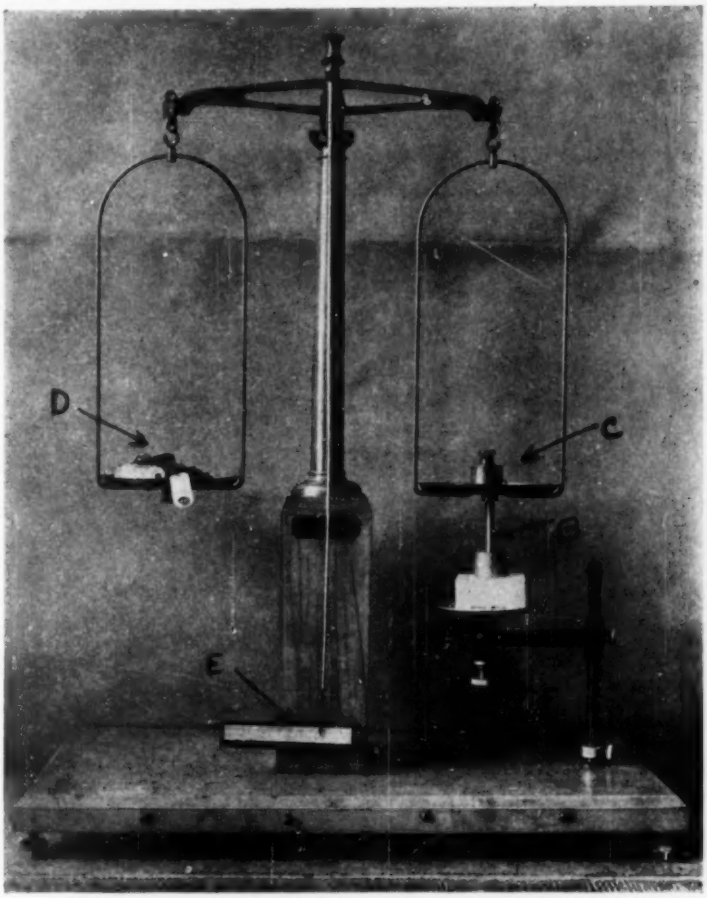

Fig. 5. Apparatus for measuring the compressibility of sponge cake.

The next sample may be cut while the previous one is being tested. The time required for adjusting and testing is approximately 1¼ minutes. Thus a large number of samples may be tested in a comparatively short time.

The choice of weights depends on the softness of the cake to be tested. Too heavy a weight will penetrate too far into the cake and result in values that are too low, due to mashing of the crumb against

the support. With cakes of 1 inch thickness, the weight should be chosen to give readings of between 10 and 25 on the scale.

The sample piece should be placed on the support, so that the face uppermost is that which was nearest the bottom of the cake. It has been found that this produces more uniform results in that the face of the block nearest the upper crust is more likely to contain irregularities, large holes, and soft areas. Usually the average of twelve pieces cut from six cakes are taken from each baking.

A measure of the elasticity or "recovering power" of the cake may also be made. After taking the reading of the compression at 1 minute, the chain is returned to the left-hand pan, and the reading taken at the end of the second minute. The cake should expand under the very small load of the slight extra weight on the plunger and return the indicator almost to zero. This duplicates closely the conditions under which a baker ordinarily determines "springiness" and can be used as a measure of this quality. This determination was not made regularly by us in testing sponge cakes.

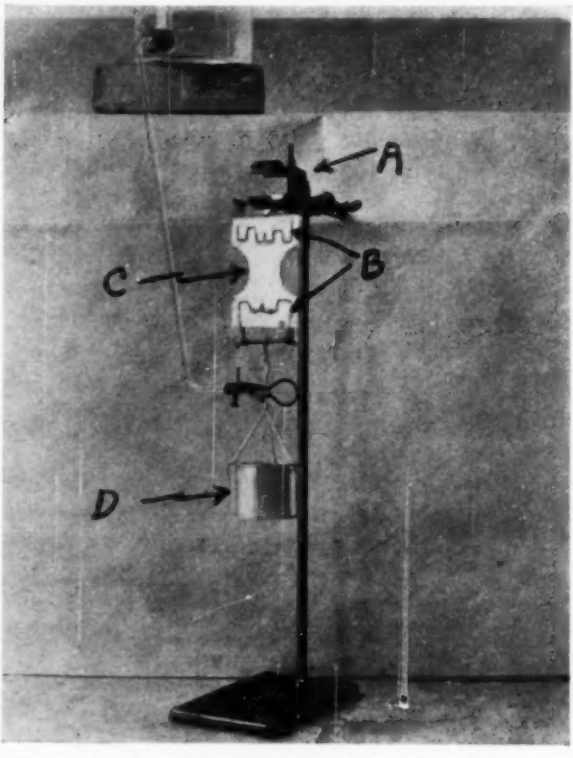

Fig. 6. Apparatus for measuring tensile strength of sponge cake.

Measurement of Toughness

Toughness is an important factor in the texture of all cakes and especially of sponge cakes. It can be measured by a determination of the tensile strength. The general method consists of cutting a piece of cake of the same shape as the test pieces of cement, rubber, or other materials where tensile strength is to be determined. A cup is hung from the bottom of this piece of cake and water run into it until the cake breaks. The details of the method are as follows:

The tensile strength of sponge cake is determined with the apparatus illustrated in Figure 6. This consists of a supporting stand (*a*); two spring clamps (*b*), which grip the ends of the test sample (*c*); a container (*d*), and a system for supplying a constant stream of water. Figure 7 shows a close-up of the sample with clamps in place and of the electric cutter used to make the indentations in the sample.

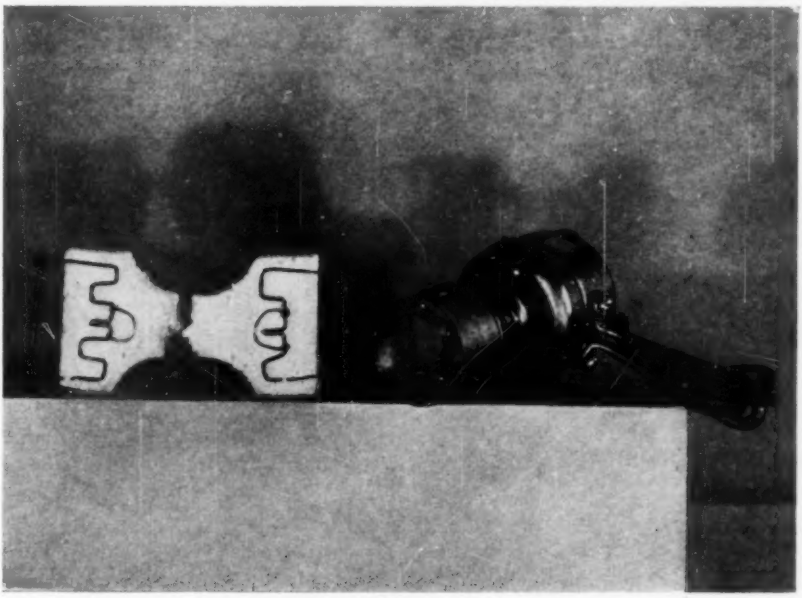

Fig. 7. Block of cake as cut for tensile strength test and electric cutter for shaping the block.

To make the test, a cake is trimmed to approximately $4'' \times 6'' \times 1''$, taking off all the crust and obtaining as far as possible uniform crumb. The neck is cut out to a width of approximately $1\frac{1}{2}''$. The neck should be of as uniform cross section as possible.

The clamps are fastened to each end of the sample so that the pull will be uniform and in a straight line directly through the center of the sample.

The sample is then hung on the support by one clamp and the container hung on the other. Water is run into the container at a rate of about 200 gms. per minute, until the limit of tensile strength is reached and the cake breaks. The container is caught as it falls and the water turned off. The container, water, clamp, and lower half of the torn sample are then weighed. This is the total weight acting on the tear. The cross section is measured at the tear and the load expressed as grams per cm^2. of cross section.

The cutter used obviates the crushing and tearing of the crumb at the neck of the sample and provides uniform cuts for all tests. Ordinarily tensile strength determinations are made on six cakes out of each baking.

The time required to perform each test is from 4 to 5 minutes. This includes cutting, testing, weighing, measuring and recording results.

The inter-relationship of the three measurements described, volume, compressibility, and tensile strength, is shown in Figure 8. This shows the effects of mixing the sponge cake batter for various

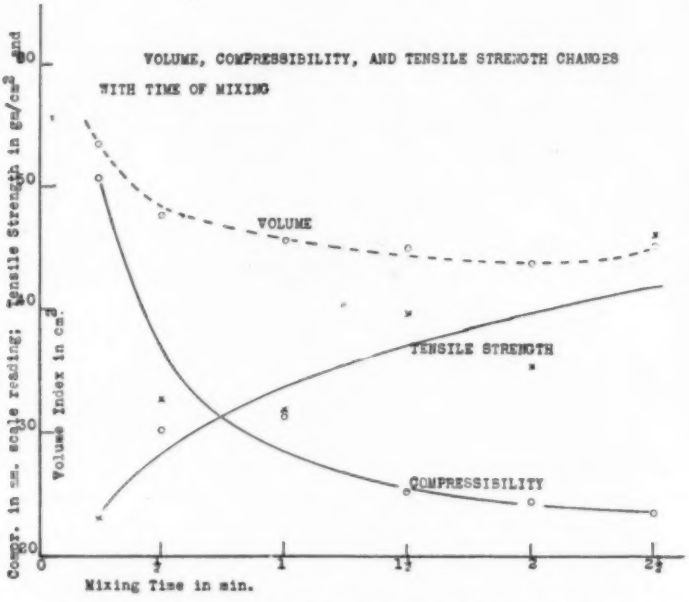
VOLUME, COMPRESSIBILITY, AND TENSILE STRENGTH CHANGES
WITH TIME OF MIXING
VOLUME
TENSILE STRENGTH
COMPRESSIBILITY
Volume Index in cm³
Compr. in sm. scale reading; Tensile Strength in gm/cm² and
Mixing Time in min.

Fig. 8. Volume, compressibility, and tensile strength changes with time of mixing.

times after the addition of flour. The results in all three tests point to a well defined "breaking down" of foam structure.

From these curves it is evident that the tests may be used indi-

vidually and/or collectively to measure quantitatively the characteristics of the cake.

In any sponge cake the grain of the upper part is more open than that of the lower. This is evidently due to the rising of bubbles in the batter after scaling and to the greater opportunity which the upper part of the cake has to expand. The upper part of the cake, therefore, has somewhat less tensile strength than the lower part which has closer grain. For this reason, in cutting test pieces for tensile strength determination, care must be taken to cut the piece from as near the center of the cake as possible, including an equal amount of the upper and lower parts.

To obviate the possible errors due to the unequal strength of different parts of the cake, experiments were made using the whole thickness of the cake as a test piece, merely trimming off the sides and cutting the circular identations as usual, but not cutting anything from the top or bottom. This method did not show any superiority over the standard method just described.

Keeping Qualities

The keeping qualities of cake,—always important,—have become even more so with modern methods of wholesale production and distribution. Cake may be weeks instead of days old before it is finally eaten.

The general principles which pertain to the staling of bread apply also to cake. These have been discussed by Platt (1930) and may be summarized as follows: The word "staling" is commonly considered as including all changes that occur to the finished cake on storage until consumed. It is not always realized that these changes are of several entirely different kinds. These normally occur simultaneously, but they are quite independent of one another. Some of these changes may be accelerated or inhibited, while the others are affected to a negligible degree.

Changes that may take place in the staling of cake stored under normal conditions are:

1. *Loss of Volatile Constituents*, i.e., "evaporation losses." Of these constituents water is by far the most important, but there are doubtless other volatile constituents in minute amounts which may contribute to the appetizing aroma of fresh cake. It is evident that these losses may be entirely prevented, as by sealing cake in a closed container. Commercially, the extent of this loss depends upon wrapping and the temperature and humidity surrounding the package.

2. *Changes Due to Oxidation.* These may be demonstrated experi-

mentally. They may be entirely inhibited by storing the cake in an atmosphere free from O_2.

3. "*Inherent Staling.*" i.e., Changes that take place apart from losses or gains from the surroundings. It is sometimes not realized that important changes in the texture of cake (and bread) take place even when moisture losses are entirely prevented.

As the evaporation losses can be so largely controlled by methods of wrapping and storage, attention in the present investigation was focused on the changes due to "inherent staling."

"Keeping qualities" are best determined by measurements of the rate of staling, this rate being determined by storing the cakes under constant conditions and measuring, from time to time, certain of the characteristics which are associated with staling. To do this requires the preparation of a large number of cakes and the ability to store them under constant conditions throughout the period of the experiment, which should be three weeks or more. With facilities for doing this, studies of the rate of staling of cakes made in different ways or kept under different conditions could easily be made. For ordinary purposes, constant storage conditions at a standard "room temperature" would be most useful. The conditions of an ordinary room, not equipped with a thermostat, are not constant enough.

For the present keeping quality experiments no thermostat large enough to hold the requisite number of cakes was available. We used a cold storage warehouse maintained at 55° F. The relative humidity was such that the cakes neither gained nor lost weight over a period of thirty-six days storage. All determinations of compressibility, tensile strength, etc., were carried out in this warehouse, so that the temperatures of the determinations were also constant.

Under these conditions a single investigation was undertaken for the purpose of working out a method for measuring the rate of inherent staling of sponge cake. While this work is by no means completed, progress to date seems to us worth reporting.

Ten dozen cakes, as uniform as possible, were obtained from one ovenful of a commercial bakery. The formula and method were in general similar to, though not identical with, those used for our standard test sponge cakes. These cakes were stored, wrapped in glassine paper, on open shelves in the warehouse described. The cakes were numbered. Weighings of many cakes at intervals showed no appreciable gain or loss of weight throughout the experiment. The following determinations were made, using the average of six cakes for each point on the curve: Tensile strength, compressibility, and ratio of compressibility when subjected to two different weights. This ratio is discussed more at length later.

The increase in tensile strength and the decrease in compressibility accompanying inherent staling are shown by the curves in Figure 9.

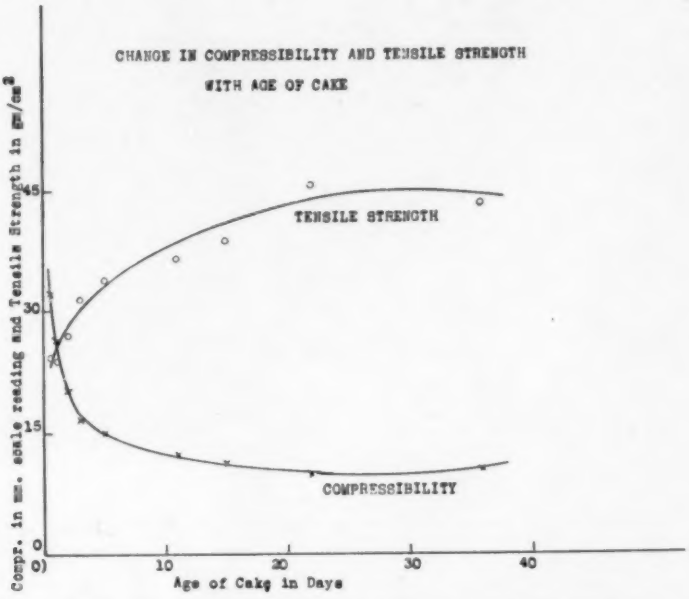

Fig. 9. Change in compressibility and tensile strength with age of cake.

It is believed that the time rate of change of compressibility or of tensile strength could be used as measures of inherent staling. These in turn, over any given period, could be best expressed as the slope of the curve or as units of change per day. In this way the relative keeping qualities of two cakes made in different ways, but kept under the same conditions, could be expressed numerically and compared.

Change in Elasticity with Age

Within the elastic limit, a perfectly elastic body should obey Hooke's Law, namely: "The strain produced is in proportion to the stress producing it." When applied to the present compressibility test, this means that if twice the weight is applied, the penetration of the plunger should be twice as great. Platt (1930) has already shown that fresh bread obeys this law quite closely over rather wide limits.

Experiments show that when fresh cake is tested for compressibility, using 200 gm. and 100 gm. weights respectively, the ratio is almost exactly the theoretical, namely 2. As the cake grows staler, however, the ratio of compressibility regularly departs more and more from the theoretical, showing that the cake is losing its elasticity.

The same change occurs in the ratio of compressibility when 300 gm. and 200 gm. weights are used. Here the theoretical ratio of 300/200 or 1.5 sinks gradually to 1.29 at the end of 36 days.

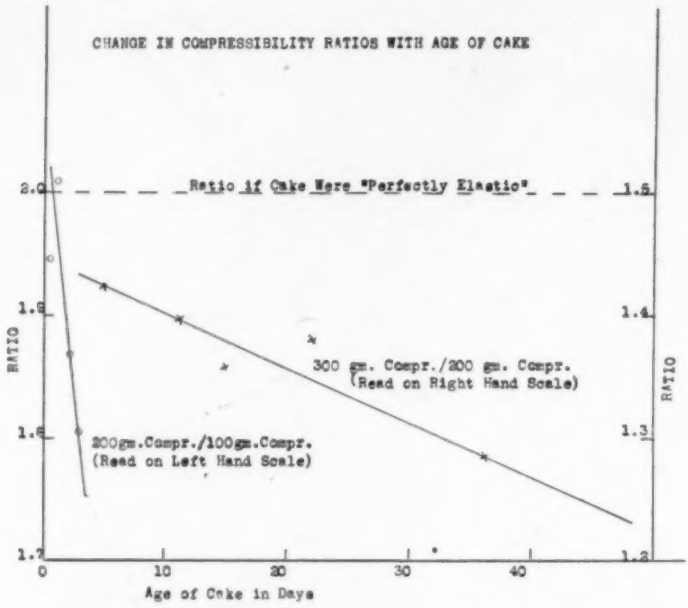

Fig. 10. Change in compressibility ratios with age of cake.

This decrease in the compressibility ratio with age of cake is shown in Figure 10 and Table I.

TABLE I

DECREASE IN COMPRESSIBILITY RATIO WITH AGE [1,2]

Age of cake	Average per cent weight change from weight at age of 12 hours	Compressibility			Tensile strength gm. per cm².	Compressibility Ratio	
		100 gm.	200 gm.	300 gm.		200 gm. / 100 gm.	300 gm. / 200 gm.
12 hours	——	16.5	32.1	—	24.4	1.95	—
1 day	+0.12	13.1	26.3	—	24.0	2.01	—
2 days	+0.03	11.75	20.1	—	26.94	1.87	—
3 days	0	9.1	16.4	—	31.5	1.81	—
5 days	+0.05	—	15.1	21.5	33.6	—	1.42
11 days	−0.05	—	12.25	17.1	36.3	—	1.40
15 days	−0.22	—	11.2	15.2	38.6	—	1.36
22 days	−0.50	—	9.7	13.4	45.6	—	1.38
36 days	−0.39	—	10.5	13.5	43.4	—	1.29

[1] Average room temperature 55° F. ± 4°.
[2] Average room humidity 70%.

This decrease in the compressibility ratio with time was first observed by the junior author of this paper. It has been observed in all of our keeping quality experiments made at various temperatures and under various conditions.

The ratio of compressibility with different weights and its relation to the theoretical ratio has the advantage that it is independent of the actual compressibility or of the previous compressibility of the same batch of cakes. Work will be continued to find whether the change in this ratio can be used as a measure of the rate of staling.

Flavor

Attempts were made to obtain a quantitative estimate of flavor, using the scoring system described by Platt (1931). As this work was undertaken primarily to determine the baking quality of eggs, the flavor of the eggs was also scored before baking.

Summary

The object of this work is to develop methods for recording the characteristics of test sponge cakes and for measuring as many of these characteristics quantitatively as possible.

The following methods for quantitative measurements are described:

(1) The specific gravity of the batter by weighing a standard cupful.

(2) Cake volume by determination of area of cross section of the cake, using a planimeter.

(3) Softness by determination of the compressibility of the crumb, using the apparatus previously described by Platt for bread.

(4) Toughness by determination of tensile strength.

The following methods for recording without actual measurement are described:

(1) Shape by drawing the profile of the cross section.

(2) Shape and grain by photography.

(3) Flavor by a careful system of scoring, using regular blanks and several judges.

Some work on the measurement of rate of staling is described. A new change on aging is noted, namely the change in degree of elasticity as indicated by the ratio of the compressibility under different weights.

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A SHORT METHOD FOR THE DETERMINATION OF GLUTEN QUALITY OF WHEAT

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Introduction

The baking quality of wheat is determined by factors which may be placed in two general classes: (1) Those that cause the gas-holding power of dough, and (2) those that influence the gas-production of dough.

The gas-holding power of a dough is dependent upon both gluten quality and gluten quantity, and power of fermentation upon the ability of the flour to furnish sufficient food material to the yeast during dough fermentation. Furthermore, there are other flour properties, which are influenced by the milling process as, for instance, the ash content, the fat content, and the method of milling, which play an important role with respect to both gas-retention and gas-production. In any event, we know that baking quality is not characterized by one single property, but that a number of properties contribute to the baking quality of flour. In the following paragraphs a short method will be discussed for the determination of gluten quality.

We begin with the conception that the volume of bread obtained in the baking process is determined by the quantity of gas which the dough is able to retain during the course of fermentation. This depends on the resistance with which gluten resists the pressure of the

fermentation gases. We may use the gas-holding power of dough as a measure for gluten quality if we use doughs which possess a continuous and uniform gas development. Flours, however, show a considerable difference in this respect, and, therefore, on account of their different fermentation ability, are not fitted for determinations of gluten quality. Gas development in whole-meal doughs, on the other hand, is very uniform, if the wheat has not germinated. For this reason, one is able to determine the gluten quality of the grain without examining the flour milled from it.

This gas-holding power of gluten, which is affected by its quality as well as by its quantity, can be most easily determined by making a dough ball from the whole-meal, mixing it with yeast and water, and allowing it to ferment in water at a constant temperature. Earlier experiments in this direction were made by Maurizio and Saunders who used flour doughs for their investigations. The dough ball, which at first sinks to the bottom, begins to rise to the surface after 10 to 15 minutes, as a result of the development of carbon dioxide gas. It is at this stage that the advantages of this method are brought out, for at this stage the dough ball is able to expand freely on all sides. This is important for the uniform development of fermentation. Being in water, the dough ball is saved from shocks. It is well known that fermenting doughs are adversely sensitive to shocks, they react instantly to all exterior influences. Furthermore, there is no danger of the surface of the dough drying out. The increasing pressure in the interior of dough causes the ball to expand more and more and finally to burst. This is followed by dissolution and sinking of dough particles to the bottom.

Recommended Method in Detail

As the handling of such small quantities of dough is sufficiently tedious, dough should be prepared for two tests at the same time and should be divided into two parts. It is extremely necessary, with this method, to make four determinations in order to get dependable results.

For each individual test, accurately weigh 5 gms. of wheat-meal 0.25 gm. of yeast, and an amount of distilled water, and knead to a dough of medium compactness in a dough dish. All whole-meals appear to have always the same water absorption capacity. Assuming that the samples of wheat have nearly the same moisture content, the difference in the absorption among samples is negligible.

The whole of the dough is now taken out of the dough dish with a spoon and kneaded by hand on a glass plate, after which a ball of dough is formed by rolling in the hands. By this procedure the

dough ball will come to the same degree of compactness and acquire a smooth surface without folds. The dough balls are first put into beakers with about 75 cc. of water at a temperature of 32° C.

Beakers 6 cm. in diameter and 7 cm. high are used. They are placed in an incubator, the temperature of which is maintained, thermostatically, at 31° to 33° C. The doors of the incubator are provided with glass panes so as to permit observation of the dough. Maintainence of the proper temperature is highly important for experimental results. Variations in temperature should never exceed 2° C. It is recommended, therefore, for the purposes of this test, that an incubator with water or air insulation be used. Time is calculated from the moment when fermentation starts (placing of the dough ball in the beaker) to the bursting of the dough ball.

Care in Preparation of Sample

For the correct use of this fermentation method, a uniform method of grinding the wheat is needed. In our work a grinder is used in which the material is milled between a grooved cone stump, turned by a vertical spindle, and a fixed grinding mantle. Disc mills, as well as mills running at high speed, are altogether unfit for this test on account of the danger of dead grinding. To avoid this, the mill must not run more than 100 revolutions per minute in distinction to the usual mills of this type which ordinarily have a much higher speed. Furthermore, the mill should be electrically driven. Only under such conditions can a uniformly ground wheat-meal be obtained from different varieties of wheat. These precautions are necessary because the degree of fineness has great influence upon the determination of gluten quality. The best procedure is to pulverize the grain in three successive stages, pouring the wheat or wheat-meal continuously into the mill at each stage. With a wide setting of the mill the grain will be ground coarsely; with a medium setting, the meal will be ground middle fine; and finally, with a close setting, the meal will become fine enough for testing purposes. In any case it is desirable that all samples should be treated uniformly throughout the process of grinding. The grinding of the wheat and the fermentation tests may be made on the same day.

Gluten Quality Test Numbers

From a large number of investigations with respect to the uniformity of gas-production in whole-meal doughs, it has been possible to assign numerical standards for gluten quality determined, as before stated, according to the time consumed from the beginning of fermentation to the bursting of the dough ball.

With regard to the test numbers, it is obvious that not only the quality of the gluten is determined, but that the quantity of gluten in the dough must have an influence on the absolute value of the results. The gluten quality itself is found by dividing the test number by the amount of gluten or protein in wheat. This quality number, bearing on the unit quantity of gluten or protein, is designated "specific gluten quality" or "specific protein quality" (Tables I and II).

TABLE I

RESULTS OF COLLABORATIVE TESTS TO DETERMINE GLUTEN QUALITY

Sample	Farinograph gluten quality (Brabender)	Baking test—bread volume (Hankoczy)	Swelling number of gluten (Berliner)	Author's results		
				Test number of gluten quality	Specific gluten quality[1]	Dry gluten
		cc.		minutes		P.ct.
Bankut 118 (spring)	98.3	443	24.0	138.7	10.1	13.7
Bankut 66	96.3	417	25.0	121.0	9.5	12.8
Bankut 1014	95.8	411	23.6	91.2	6.9	13.3
Szekacs 1055	95.8	401	20.0	71.0	6.2	11.5
Szekacs 1242	89.3	383	22.8	42.0	3.6	11.7
Bankut 121	83.0	392	17.6	42.5	3.0	13.9
Bankut 1205	82.7	392	8.6	38.2	2.8	13.7
Bankut 1201	82.3	396	12.8	36.7	2.8	13.2
Hatvan 3490	82.0	358	14.4	30.7	2.7	11.2
Szekacs 1510	81.5	333	11.8	31.0	2.9	10.8
Szekacs 1385	79.4	315	15.2	30.2	2.7	11.3
Bankut 118 (winter)	76.9	384	8.0	30.0	2.7	10.9
Hatvan 1119	74.9	318	1.0	23.2	1.8	12.9
Szekacs 1446	74.6	367	9.0	27.0	2.4	11.4
Hatvan 1153	73.4	344	8.6	26.0	2.4	11.0
Mindszenti 403	71.7	330	8.0	31.0	2.6	12.1
Esterhazi 18	70.1	348	7.5	24.5	2.2	11.0

[1] Test number in minutes divided by gluten content of wheat.

Table I contains the results of some baking tests made on some Danubian wheats which have been examined by the Kgl. Ungarische Versuchsanstalt für Getreideverarbeitung, Budapest (Hungary), together with (1) quality numbers by the Farinograph (Brabender, 1931-1932); (2) swelling results of the gluten determined by the Forschungsinstitut für Getreidechemie of E. Berliner, at Darmstadt (Germany); and (3) our test number with the fermentation method above described. These investigations were recommended by Director A. Manniger, Nemetboly (Hungary). The determinations were carried out at the three places, no laboratory knowing the results of the others as the samples were ciphered.

Table II records the results of some tests made at the Grain

Research Laboratory of the Board of Grain Commissioners, Winnipeg, Canada.

TABLE II

BAKING DETERMINATIONS AND QUALITY NUMBERS BY THE FERMENTATION METHOD

Sample	Baking test [1]			Fermentation method		
	Bread volume	Texture of crumb	General baking quality	Test number of gluten quality	Specific protein quality [2]	Protein content
	cc.	score		minutes		P.ct.
Canadian No. 1 hard	2990	6	Excellent	117.5	6.74	17.4
Kansas	2970	8	Good	104.3	7.45	14.0
Canadian No. 3 Northern	2965	8	Very good	101.0	6.20	16.3
Canadian No. 2 Northern	2800	8	Good	110.0	7.10	15.5
Canadian No. 1 Northern	2750	7	Good	109.9	7.02	15.7
Australian wheat	2160	7	Very fair	42.6	3.55	12.1
French wheat	1955	8	Fair	36.0	3.40	10.6
German No. 2	1900	6	Fair	29.9	2.88	10.4
German No. 2	2200	6	Poor	30.2	2.56	11.8
Argentine No. 2	2100	7	Poor	43.9	3.28	13.4
English No. 2	1840	7	Poor	31.0	2.67	11.6
Danubian No. 2	1730	3	Very poor	29.2	2.15	13.6

[1] Baking tests made at the Grain Research Laboratory (Board of Grain Commissioners), Winnipeg, Canada.

[2] Test number in minutes divided by protein content of wheat.

In all cases there appears to be a good agreement between the results obtained by the baking tests and by our gluten quality determinations, as well as by the quality numbers obtained with the Farinograph, and by the swelling method of Berliner and Koopman (1927, 1929). The latter method is the most widely used for the examining of gluten quality in the milling and baking laboratories of Europe, and our own determinations.

TABLE III

GLUTEN QUALITY VALUES FOR SOME SAMPLES OF WORLD WHEATS

Variety	Gluten quality, test number in minutes
Northern Spring	160–280
Manitoba	80–240
Hard Winter	25–110
Russian	20– 60
Barusso	25– 50
Australian	25– 35
Hungarian	20– 40
Squarehead's Master	12– 25

Gluten Quality of Wheat in International Trade

The computable differences found for gluten quality in different types of wheat are extremely large. Some samples of world wheats are grouped in Table III.

The order of quality of these wheats corresponds to that of their baking results and agrees with the usual estimations of the milling and baking industry. The test number 30 is apparently the limit between superior and inferior gluten quality.

Practical Significance of the Dough-Ball Method

It is generally recognized that the baking experiments are subjective and that they show different results for the same flour according to the baking method used. All that can be stated, as a result of the ordinary baking investigations only, is that the flour, baked under certain conditions, has a good or an inferior baking quality, but it does not show *why* the flours have this or that baking quality.

For these reasons, the fermentation method described above is a valuable contribution to the baking researches of our milling and baking laboratories for it offers a means of characterizing the baking values of wheat and flour by determining the diastatic power and the ash content together with the quantity and quality of gluten. It enables the miller to buy the most desirable wheats and to mix them in the most advantageous and profitable manner.

As flour improvement also has to take account of original gluten quality, the fermentation method gives valuable information for the correct improvement of flour. The better the gluten quality and the smaller the ash content, the smaller the amount of persulphate of ammonia which will need to be added to the flour to secure the best baking results.

A comparison of experimental investigations carried out in connection with milling laboratories, each using different baking methods, with the results of our own gluten experiments with the fermentation method on a total of more than 200 different samples of wheat, showed that there is good agreement with the baking results. When one takes into consideration the variations in milling and the differences in the diastatic power of the flours, the efficiency of the fermentation method is obviously established.

The fermentation method enables the milling industry to obtain from small samples computable data for gluten quality in a very short time. As far as equipment is concerned, all that is needed is a small mill for grinding, an incubator, beakers, and implements for preparation of the dough. One person can make about 150 to 200 experiments

per day including the grinding of the grain. Thus millers will be able to make tests upon lots of wheat which they contemplate purchasing.

Furthermore, the method is very useful for the determination of gluten quality of wheat varieties and strains. To develop new wheat varieties that outyield those grown at present, and that at the same time have superior milling and baking qualities, a short method for use on small samples is needed. By the fermentation method, there may be secured at least a partial understanding of the mode of inheritance of the very complex characters which are concerned in the question of quality or "strength" in wheat.

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BOOK REVIEW

pH and Its Practical Application. By Frank L. LaMotte, William R. Kenny, and Allen B. Reed. Published by Williams & Wilkins Company, Baltimore, 1932. 262 pages. Price $3.50.

This very readable book is divided into two parts. The first section deals with the mechanism of hydrogen-ion determinations and, after a brief introduction, includes chapters upon hydrogen and hydroxl-ions, buffer action, determination of pH, and sources of error. The theories of pH are put into simple language and expressed with unusual clearness. There is, however, one very serious omission in this exposition. In a book with the title "pH and Its Application," any person at all familiar with the subject would certainly expect to find at least some information concerning the use of the electrometric method in pH work. It is not fair to the purchaser of the book to dismiss this phase of the work, as is done upon page 23, with the statement that "Since all electrometric methods require considerable experience and skill on the part of the operator, the full benefits to be derived from its use are limited to those possessing this skill. References to this technique will therefore be made only in the interests of the principles involved, and the discussion will be confined strictly to the colorimetric method."

While the hydrogen electrode may be troublesome to the unskilled operator, the technique of the quinhydrone electrode and of the antimony electrode is not difficult and there will probably be many plant operators who, in the light of the vast amount of practical information in this book, will want to know of what service the electrometric methods can be to them. The book as it stands should more properly be entitled "The Colorimetric Method of Determining pH and its Practical Application." Then too, the addition of a chapter on colorimetric test papers might be of great service to the ordinary "works" man.

The second section of the book under the heading, "Practical Application of Hydrogen-ion Determinations in Industry and Science," contains chapters on municipal and industrial water supply, water corrosion problems, disposal of sewage and industrial waste, sugar, gelatin and glue, leather manufacture, textile industry, pulp and paper industry, food industries (including flour, dough, bread, and crackers), cleaning processes, electrodeposition of metals, general industrial chemistry, bacteriology, pathology and titration processes as well as soils. The reader will obtain much important information concerning these industries in addition to that concerning the application to them of the colorimetric methods of pH. Of course, in the brief space available the information is by no means complete, yet a reader engaged in any of these industries would certainly find information of value to him and suggestions which should start him thinking. The authors have apparently tried to give a straightforward interpretation of the value of pH to these industries, yet the reviewer feels that very often its significance is overestimated. For example, in the chapter on soils we read, page 234, "The pH of soil also determines the presence of aluminum." It can be said equally well that aluminum determines the pH of soils, or more accurately perhaps, that it is a factor in determining the pH of soils. The assumption is made throughout the work that the pH value of any solution as measured by the hydrogen electrode is the last word in accuracy. This will not always be true.

Errors are few in this book, but it is startling on page 132 to read that fresh milk of pH 7.16 may contain 86% of carbon dioxide. What it meant is that 100 parts of milk by volume may contain 86 parts by volume of CO_2 in solution. The charts accompanying each chapter which indicate the important pH zones in the field considered in that chapter are very useful. The list of plants with their soil preferences, pages 240 to 252 is very valuable to any gardener and probably this phase of the subject is deserving of more emphasis than is given here.

In reviewing this work the writer has assumed that the book was written primarily for the works man of limited scientific knowledge, in an effort to show him the practical value of pH in his plant. If colorimetric methods satisfy his needs this is his book, but if he wants a more complete popular treatise dealing also with electrometric methods he will have to look elsewhere.

ALAN LEIGHTON

BULLETIN REVIEWS

Inter-Society Color Council. Bulletin No. 1, June 7, 1932. M. Rae Paul, Secretary, 105 York Street, Brooklyn, New York.

This Council is a development from a widespread demand in art and industry for greater uniformity in the designation and standardization of colors. In this bulletin the objectives of the organization are listed and progress reports given of several committees appointed to study (1) color problems in general, (2) color measurements and color specifications, and (3) color names. Subsequent bulletins are to be published from time to time to acquaint members of the Council with Inter-Society activities.

The bulletin is available to members and cooperating associates.

D. A. COLEMAN.

The Drying of Wheat (Second Report). By E. Stansfield and W. H. Cook. Dominion of Canada National Research Council, Report No. 25, Ottawa, 1932.

This report is a continuation of the study previously reported upon (N. R. C. Report 24, 1929) with respect to the storage and commercial drying of damp wheat with particular reference to the effect of drying conditions upon the milling and baking quality of wheat.

The main body of the report concerns itself with a description of a new experimental grain dryer, and the results of experiments made with this dryer covering almost every phase of grain drying problems. The report states that further investigations with commercial dryers were unavoidably limited by the small amount of damp and tough grain received at terminals during 1928, 1929, and 1930.

The effect of various conditions of drying upon the milling and baking properties of wheat were studied. Under the conditions of the drying technique tried, no injury to milling quality was found. The baking quality, however, showed injury under certain conditions. Hot air temperatures are most influential. 180° F. was found to be the maximum safe temperature for the drying air; above this limit the extent of injury to baking quality increases with temperature and rate of drying. The bromate differential test appears to be the most effective in detecting the type of injury caused by heat drying. The extent of injury is not dependent upon the initial moisture content of the wheat. Grain of high or low moisture can be dried with equal safety provided an air temperature of 180° F. is not exceeded and rate of drying is not excessive. The double stage method of drying unusually damp wheat has no advantage and is not recommended. Weather conditions (cold weather, excessive humidity, etc.) were also studied and found to have no effect on baking quality; drying efficiency alone being modified. Batch drying was found to involve somewhat more of a risk to baking quality than continuous drying, but if temperatures below 180° F. are used batch drying was satisfactory. The effect of drying is no more harmful to the lower grades of wheat than to the higher grades, popular opinion of some to the contrary.

In the appendix are to be found further studies with commercial dryers, a review of the literature on the bin drying of wheat, the methods of analysis used in the investigation, and an interesting article with respect to the influence of heat treatment on the baking behavior of flour as determined by different baking formulae.

D. A. COLEMAN.